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RESEARCH ON ARCTIC FRONTAL PASSAGES IN SOUTHERN ALBERTA

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Research on Arctic Frontal Passages in Southern Alberta", submitted by Beverley Murray Burns in partical fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

This study is based on data extracted from surface and 500-mb synoptic charts which satisfied certain criteria of arctic frontal passage, for the months of November through February and over the seven year period 1958 to 1964.

The object of this study was the formulation of practical methods of prediction which could be easily applied by the field forecaster. With this goal in mind, an analogue method was developed which enables the forecaster to classify both the type and time of occurrence of arctic frontal passages at Edmonton, Calgary, and Lethbridge. It was found that there are seven types of arctic frontal passage, of which Type I is most prevalent, in the period under consideration.

It is also shown how overlays may be constructed and used for forecasting by the field meteorologist.

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Introduction

The purpose of this research is two-fold in that it attempts to arrive at a method of predicting both the occurrence and time of arctic frontal passages at Edmonton, Calgary, and Lethbridge. These three stations were used, since the arctic air, after penetrating Northern Alberta, frequently remains there for an extended period of time prior to moving southward.

This study was selected with a view to formulating practical methods of prediction which could be easily applied in field operations.

In this investigation a five-front model had to be used for the adequate description of typical synoptic situations. This was found to be necessary because various "intermediate" fronts were carried on the surface analyses used in the study, and because it has been found from experience that these fronts do in fact exist, especially in the winter, when they often present the major forecasting problem. The five-front model is based on the Canadian three-front model as described by Buckler[1]: " The addition of upper air data in the 1940s to our body of facts supplied a new dimension to the study of air masses and fronts. In this Canada led the way. The

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[1] S. J. Buckler, " The Structure Of Fronts And The Occlusion Process ", Training Section - Meteorological Branch - Department Of Transport - Canada, Internal Publication, Toronto, p. 2.

development of frontal contour analysis in Canada led to the paper by Crocker, Godson, and Penner (1)[2] showing that frontal surfaces were often continuous around the world at higher levels. Although such a condition implied a contradiction of the original Norwegian theory requiring convergence of two air masses, confirmation followed from studies by Bradbury and Palmen (2)[3] and Palmen and Nagler (3)[4]. The Canadian School further demonstrated in Godson (4)[5], the existence of 4 air masses and on occasion 5 air masses. This required an extension of the Norwegian Theory to embrace 3 fronts and 4 air masses ". In the sense and spirit of the foregoing, the five-front model is thus simply a pragmatic extension of the standard Canadian three-front model, adapted to take account of the multiplicity of hyper-baroclinic zones so commonly found in winter.

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[2] A. M. Crocker, W. L. Godson and C. M. Penner, " Frontal Contour Charts ", J. Meteor., 3, 1947, pp. 95-99.

[3] D. L. Bradbury and E. Palmen, " On The Existence Of A Polar-Front Zone At The 500-MB Level ", Bull. Amer. Meteor. Soc., 34, 1953, pp. 56-62.

[4] E. Palmen and K. M. Nagler, " The Formation And Structure Of A Large-Scale Disturbance In The Westerlies ", J. Meteor., 6, 1949, pp. 227-242.

[5] W. L. Godson, " The Structure Of North American Weather Systems ", Quart. J. Roy. Meteor. Soc., London, Centenary Proceedings, 1950, pp. 89-106.

Table 1 lists the air masses and fronts considered in this study. The air masses are defined in terms of appropriate ranges of the wet bulb potential temperature Θ_w .

DEFINITION OF RANGES : AIRMASSES AND FRONTS

RANGE	AIRMASS	FRONT
$\Theta_w \geqslant 16$	mT maritime Tropical	P Polar
$16 > \Theta_w \geqslant 12$	mP maritime Polar	
		mA maritime - Arctic
$12 > \Theta_w \geqslant 8$	mA maritime Arctic	
		tcA transitional continental - Arctic
$8 > \Theta_w \geqslant 4$	tcA transitional continental Arctic	
		A main - Arctic
$4 > \Theta_w \geqslant 0$	A continental Arctic	
		A_1 Arctic
$0 > \Theta_w$	A_1 Arctic	

TABLE 1

No wide-ranging discussion of air mass and frontal theory will be attempted here, since these topics are treated exhaustively in numerous meteorological texts and papers. Following the originators of the

Norwegian polar frontal theory[6], it will be assumed that, in the strictest sense, there are only two major source regions in each hemisphere: the subtropical oceans where maritime tropical air originates, and the polar zone, the source of polar air. All other air masses result from modification of these two "primary" air masses due to trajectory. From this point of view the classical polar front is the dominant discontinuity between the cold air and warm air masses, but other discontinuities will develop as well between contiguous masses of modified air. Thus it is often possible and necessary to introduce secondary or "intermediate" fronts, particularly in winter, provided of course that they are of meteorological significance.

Table 2 lists the station data and abbreviations which will be used in this thesis.

LIST OF ABBREVIATIONS

LOCATION IDENTIFIERS	NAME	GEOGRAPHIC LOCATION		ELEVATION (FEET)
VQ	Norman Wells, N.W.T.	65°17'N	126°48'W	209
SM	Ft. Smith, N.W.T.	60°01'N	111°58'W	665
YE	Ft. Nelson, B.C.	58°50'N	122°35'W	1230
XY	Whitehorse, Y.T.	60°43'N	135°04'W	2289
QD	The Pas, Man.	53°58'N	101°06'W	894
XD	Edmonton, Alta.	53°34'N	113°31'W	2219
XS	Prince George, B.C.	53°53'N	122°41'W	2218
YC	Calgary, Alta.	51°06'N	114°01'W	3540
QL	Lethbridge, Alta.	49°38'N	112°48'W	3018
GTF	Great Falls, Mont.	47°29'N	111°22'W	3671

TABLE 2

[6] V. Bjerknes, J. Bjerknes, H. Solberg and T. Bergeron, 1933: Physikalische Hydrodynamik, Berlin, Julius Springer Verlag, pp. 702-722.

No attempt was made to classify the various types of arctic frontal passage with regard to the severity and characteristics of the associated weather. This problem is complex and would have required considerably more time to investigate. Furthermore, to quote Penner[7], " The front by itself then does not explain weather ... weather systems have to be studied on another scale ". For similar reasons, it was not possible thus far to test the method operationally in a forecast office. However, a testing programme is planned for the coming winter at the Edmonton International Airport. Stewart[8], who developed an overlay analogue method for predicting cold waves at Chicago, tested his method. His criteria are essentially identical to the ones employed in this study, the main difference being that his method is based on the use of current charts only. The results of his testing are as follows:

(1) Employing a quite stringent definition of a cold wave, he verified 75 per-cent on a dependent sample of 44 cases. However, based on the criteria of cold frontal passage as used in this investigation, his sample verified at 93 per-cent.

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[7] C. M. Penner, " The Scales Of Meteorological Phenomena ", Training Section - Meteorological Branch - Department Of Transport - Canada - Internal Publication #60, 1963, p. 5.

[8] P. G. Stewart, " Investigation Of Cold Waves At Chicago, Illinois ", The University Of Chicago, Department Of Meteorology, Scientific Report No.9, Contract No.AF19(604)-2179, March 1959, 20 pp.

(2) On a 93-day independent sample, in which there were 2 cases, he verified at 50 per-cent, while a second test, carried out independently by another meteorologist, verified at 100 per-cent on the basis of his definition of a cold wave. The difference in the accuracy of the two tests arose from the evaluation of the critical parameters on the borders of his overlays. This problem will be discussed in more detail later;

(3) A check was also made on the applicability of the method to a month outside the range of his sampling interval. In an eight-year test he verified at 33 per-cent. However, it is likely that his verification score would have been higher if he had used the less stringent cold frontal passage criteria.

Chapter 1

A Selection and Analysis of Synoptic Data :

The first consideration was the stipulation of the criteria which were to be fulfilled in order that a case be worthy of study. Such cases were selected as follows:

(1) the main arctic front (A) had to pass the three stations;

(2) the arctic air had to remain over the region for at least twenty-four hours.

The frontal passage time was selected according to the following three criteria, specified in terms of Δt, the difference in frontal passage time between A and tcA, :

(1) if $\Delta t \leqslant 2$ hours or $\Delta t > 18$ hours, then the A frontal passage was chosen;

(2) if $2 < \Delta t \leqslant 12$ hours, then the average of the frontal passage times was chosen;

(3) if $12 < \Delta t \leqslant 18$ hours, then the frontal passage time chosen was $t_{tcA} + \frac{2}{3} \Delta t$, where t_{tcA} is the passage time of the tcA front (see Table 5 and Tables 1 to 7 Appendix B).

The frontal passage time was selected according to passage time criterion (1), because there was only one distinct short wave trough associated with the arctic front. Criteria (2) and (3) were applied to cases involving two short wave troughs, associated respectively with the tcA and A fronts. In the first case the location of the short wave trough relative to the arctic front presented no problem. The second and third cases presented problems in that the primary short wave trough affected the flow so as to obscure at times the secondary

short wave trough. Thus it was necessary to introduce time averaging in order to smooth the errors in the positioning of the pertinent short wave trough. The errors so introduced, in the location of the short wave trough relative to the arctic front, likely contributed to the scatter of the short wave trough positions as illustrated in Figures 2.5, 3.5, .. etc .., 7.5. It was also deemed necessary to include "fresh outbreaks" in the investigation, in situations when Southern Alberta was still covered by a modified arctic airmass. A "fresh outbreak" was defined as the passage of the A_1 front through the region in an established 500-mb pattern of a particular type as illustrated, for example, by the 500-mb charts in the upper right hand corner of Figures 2.1, 3.1, .. etc .., 8.1.

The investigation was approached as a fixed time study of the surface and 500-mb situation - where fixed time refers to the time of frontal passage. Since accurate computer prognoses are now available, it was felt that a study from this point of view would be of most use to the field forecaster. A second approach would be to use numerical analysis, employing various statistical techniques, with the aim of producing prediction equations. The disadvantage of this method is the enormous amount of data processing required to generate satisfactory results.

The data were extracted from the existing charts at the Edmonton International Airport for the months of November through February and over the seven year period 1958 to 1964. The selection of months was in a sense arbitrary, but was considered as covering the major portion of the winter season. The period covered was largely

dictated by the availability of both time and data. The air mass analyses were extracted from the Edmonton Weather Office Frontal Contour Analysis (F.C.A.). All charts used in this study were re-analyzed in order to maintain continuity and structural consistency.

Fifty-three cases were considered, of which seventeen (32%) were "fresh outbreaks" (see Table 3). For each case the following data were recorded:

(1) the position, at frontal passage time, of

(a) the 500-mb cold low, short wave trough, and long wave ridge;

(b) the surface high and low centers or wave associated with the front.

Historical continuity was maintained by beginning the analysis at two or more radiosonde observation times prior to passage at Edmonton, and extending it to the radiosonde observation time following passage at Lethbridge (covering a period (Y) in the interval $12<Y\leq 72$ hours).

It was decided to display the upper air and surface data, for each type of arctic frontal passage deduced from the analysis, in terms of areas of percentage positional occurrence, and to list the percentage occurrence within a given radius, expressed in degrees latitude from the center of the cluster[1]. The cluster is a set of points (centers

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[1] Figures 2.4, 2.5, 3.4, 3.5, 4.4, 4.5, 5.4, 5.5, 6.4, 6.5, 7.4, 7.5, and Tables 1 to 6 Appendices F and G.

TYPE	Number of "Fresh Outbreaks" Per Type	Percentage[2] of "Fresh Outbreaks" Per Type	"Fresh Outbreaks" all Types Number	"Fresh Outbreaks" all Types Percentage
1	11	38	17	32
2	3	43		
3	0	0		
4	1	17		
5	1	25		
6	1	25		
7	0	0		

TABLE 3

[2] Percentages computed on the basis of a total number of fifty-three cases. The total number of cases per type is listed in Table 4 on page 7.

of highs or lows) arising from the contribution of each case to a given type. The center was determined by drawing a triangle around the region of maximum density and taking the center of the triangle as the cluster center. The area of percentage positional occurrence is the percentage of the total number of cases of a given type which are found within a designated area, and the percentage occurrence within a given radius is the percentage of the total number of cases of a given type which are found within the circle described by that radius. These radii and areas are listed in the tables of Appendices C and D .

Four cross-sections were constructed for selected cases to illustrate the magnitude of various frontal slopes and the general shape of the arctic high (see Figures 2.2, .. etc .., 8.2). The distance from the stations, normal to the front, may be determined from the corresponding Figures 2.1, .. etc .., 8.1.

There are two east-west cross-sections: the first extends along 60°N from Ft. Smith to Ft. Nelson to Whitehorse, and the second extends along 53.6°N from The Pas to Edmonton to Prince George, the distances between stations in both cases being measured in degrees latitude. The two north-south cross-sections, normal projections on the 113.5°W meridian, are as follows: Norman Wells to Ft. Nelson to Edmonton to Great Falls, and Norman Wells to Ft. Smith to Edmonton to Great Falls. This is illustrated in Figure 1.1.

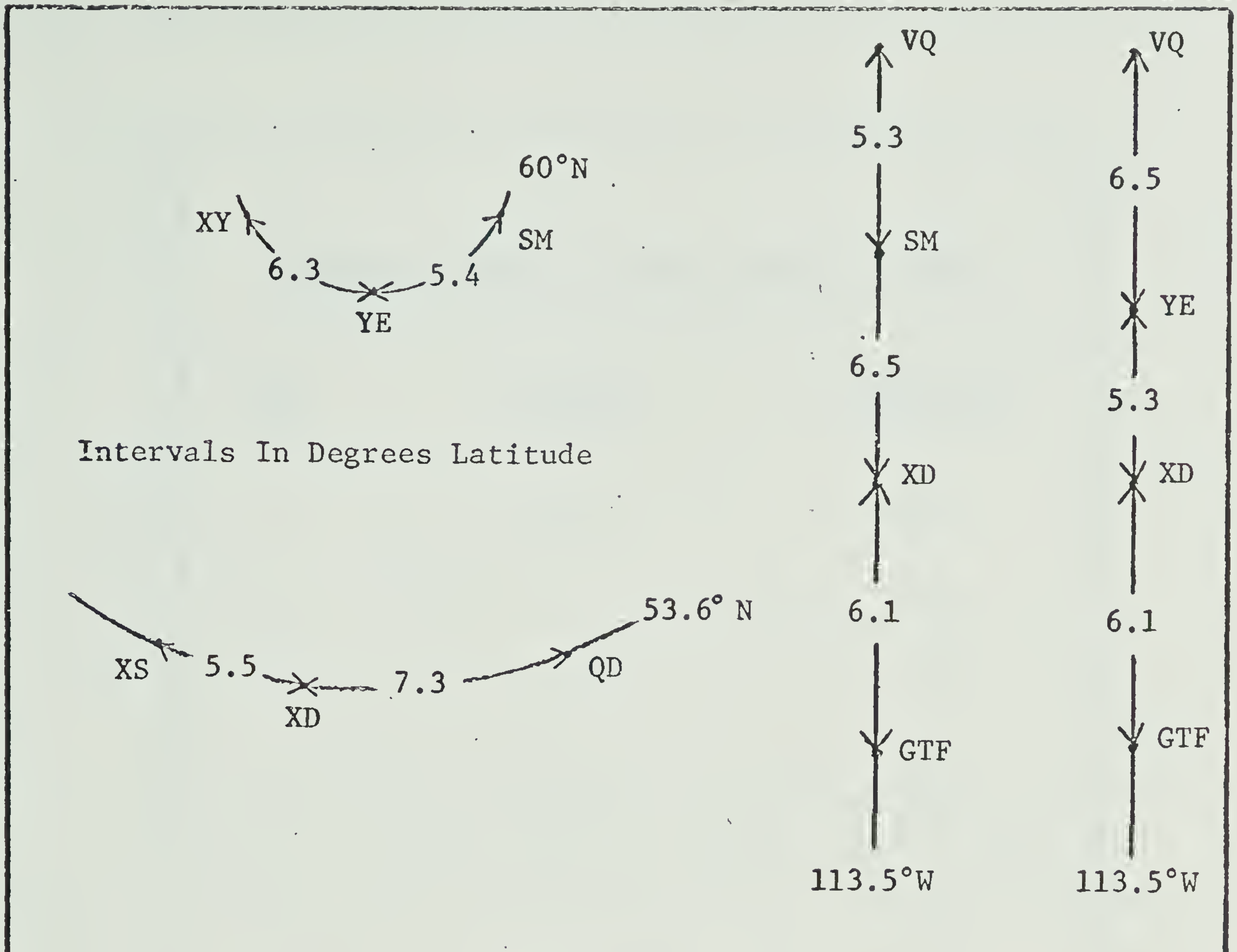


FIGURE 1.1

B Synoptic Typing and Selection of Criteria

From the analysis of the 500-mb and surface configurations, it was found that there were seven distinct synoptic situations causing arctic frontal passages at Edmonton, Calgary and Lethbridge. These are labeled Type I through Type VII. A complete listing of all types and cases is given in Appendix A. Table 3 lists the contribution of "fresh outbreaks". The number of cases in each type, with their percentage contribution to the total, are listed in Table 4. Table 5 shows the results of time averaging mentioned in Section A.

NUMBER OF CASES OF ARCTIC FRONTAL PASSAGE

TYPE	PER TYPE	PERCENTAGE
1	29	55
2	7	13
3	2	4
4	6	12
5	4	7
6	4	7
7	1	2
	53	100.0

TABLE 4

TYPE	CASES INVOLVING TIME AVERAGING OF FRONTAL PASSAGES[3] (HRS.)							
	AVERAGE TIME (HRS.)			TYPE OF AVERAGE			PERCENTAGE OF TOTAL CASES PER TYPE	PERCENTAGE OF TOTAL CASES
	XD	YC	QL	XD	YC	QL		
1	1.5	1.5	2.0	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$	45	
	1.5	12.0	12.0	$\Delta t/2$	$+\frac{2}{3}\Delta t$	$+\frac{2}{3}\Delta t$		32
	2.0	1.5	2.0	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$		
	3.0	1.5	2.0	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$		
	5.5	3.0	3.0	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$		
	8.5	8.5	6.0	$+\frac{2}{3}\Delta t$	$+\frac{2}{3}\Delta t$	$\Delta t/2$		
	3.0	6.0	6.0	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$		
	3.0	3.0	3.0	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$		
	1.5	3.5	4.5	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$		
	5.0	2.0	3.0	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$		
	12.0	6.0	6.0	$+\frac{2}{3}\Delta t$	$\Delta t/2$	$\Delta t/2$		
	2.0	12.0	12.0	$\Delta t/2$	$+\frac{2}{3}\Delta t$	$+\frac{2}{3}\Delta t$		
	0.0	2.0	2.0	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$		

TABLE 5 (cont.)

[3] See next page

TYPE	CASES INVOLVING TIME AVERAGING OF FRONTAL PASSAGES[3] (HRS.)							
	AVERAGE TIME (HRS.)			TYPE OF AVERAGE			PERCENTAGE OF TOTAL CASES PER TYPE	PERCENTAGE OF TOTAL CASES
	XD	YC	QL	XD	YC	QL		
4	3	3	3	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$	33.3	
	0	6	2	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$		
5	9	9	9	$+\frac{2}{3}\Delta t$	$+\frac{2}{3}\Delta t$	$+\frac{2}{3}\Delta t$	25	
6	1.5	1.5	1.5	$\Delta t/2$	$\Delta t/2$	$\Delta t/2$	25	
Mean[4]	3.6	4.8	4.6					
STD. DEV.	3.3	3.5	3.3					

TABLE 5

[3] Using column one with column two, the time interval between the passage of the tcA and A fronts may be determined.

[4] This is the mean of the averages between frontal passage times and gives an estimate of the error introduced due to the averaging.

The various types were classified according to the 500-mb and surface configurations, using the following criteria:

(1) the position, at frontal passage time, with respect to Edmonton, Calgary and Lethbridge, of

(a) the 500-mb cold low,

(b) the 500-mb short wave trough,

(c) the 500-mb long wave ridge, west of Alberta,

(d) the pertinent surface highs,

(e) the pertinent surface lows,

(f) the pertinent surface frontal wave if separated from the low;

(2) the trajectories, over the time interval defined on p. 3, of

(a) the pertinent surface highs,

(b) the pertinent surface lows,

(c) the pertinent surface frontal wave if separated from the low.

Figures 2.1 through 8.1 illustrate these configurations. Figures 2.4 through 7.4 and 2.5 through 7.5 show the percentage enclosure; each designated area encloses a certain percentage of the total number of cases. Where the area of enclosure specifically refers to high or low centers, the center of a cluster is designated by either a dot or the most interior apex of one of the areas.

On the surface trajectory charts, the dashed lines indicate the trajectories of lows, the dotted lines indicate the frontal wave (WV) trajectories, and the solid lines indicate the trajectories of highs (see Figures 2.3, .. etc .., 8.3). The dashed lines, on the

500-mb percentage area charts, indicate the short wave trough positions, while the solid lines indicate the long wave ridge positions (see Figures 2.5, .. etc .., 7.5, and 8.4).

Table 6 is a summary of the synoptic typing deduced from the surface and 500-mb configurations of all cases investigated. Using this table it is possible to determine the general description of a given type. This is done by making seven overlays, each corresponding to a given type, from the data given in Table 6. These overlays should be made of transparent sheeting, such as acetate or plexiglass, with holes in the positions corresponding to the listed X's for each type. For the sake of brevity, the term 'gradient', when used by itself in Table 6, always refers to a pressure gradient.

The following chapter contains the sets of figures describing each type beginning with Type I and progressing in order through to Type VII.

TABLE 6

A SUMMARY OF THE RESULTS ARISING FROM THE SURFACE AND 500-MB CONFIGURATIONS

SURFACE INITIALLY THERE IS	TYPE I	 II	 III	 IV	 V	 VI	 VII
1. a high or ridge located over Alaska, the Yukon or the Mackenzie Basin (from the sector 250° through 360°) with a strong gradient north of the arctic front in the region of maximum penetration of the arctic air;	x	x	x	x	x	x	x
2. a system of fronts, lying northwest to southeast, through Northern Alberta;	x		x		x		x
3. a U-shaped system of fronts, such as shown in figure 3.1, in British Columbia;		x					
4. a system of fronts, lying west to east, through Northern Alberta;				x		x	
5. an intense high lying in the region 40°N to 55°N, 110°W to 137°W, (region H) with a ridge extending northward through British Columbia;	x		x				x
6. a high lying in the region 71°N to 72°N, 97°W to 100°W;							x
7. a flat ridge (from the south) located over British Columbia;					x	x	
8. an intense high lying in the region 60°N to 80°N, 120°W to 180°W;		x			x		

SURFACE INITIALLY THERE IS	I	II	III	IV	V	VI	VII
9. a frontal low in the region 55°N to 60°N, 120°W to 145°W;			x	x			
10. a frontal low or wave approaching the British Columbia coast or in its vicinity;		x					x
11. a secondary frontal low in the region 58°N to 65°N, 107°W to 120°W;			x	x			
12. a frontal low in the vicinity of Great Bear Lake;					x		
13. a deep low in the Gulf of Alaska;							x
14. a frontal wave either separated or becoming separated from low.		x					
AFTER THE COLD AIR HAS COVERED ALBERTA THERE IS							
1. a high in the region 60°N to 70°N, 118°W to 150°W;	x	x	x	x		x	x
2. a high in Northern Alberta, Northern British Columbia or in the region 68°N to 75°N, 145°W to 155°N;					x		
3. a high in the region 53°N to 55°N, 100°W to 103°W;							x
4. a weakening of the intense high in region H and collapse of ridge over British Columbia;	x		x				x
5. a ridge southward to southeastward from high;	x	x	x	x	x	x	
6. a gradient in Southern Alberta with :							
(a) northerly flow ,				x	x	x	
(b) easterly flow ,	x		x				
(c) southerly flow ;		x					

SURFACE AFTER THE COLD AIR HAS COVERED ALBERTA THERE IS	TYPE I	II	III	IV	V	VI	VII
7. a deep low in the Northern United States west of the Great Lakes.				x		x	

500-MB INITIALLY THERE IS	TYPE I	II	III	IV	V	VI	VII
1. a westerly to west-northwesterly flow over Alberta;	x	x	x	x	x	x	
2. a northerly flow over Alberta;							x
3. a short wave trough moving southward through Alaska, the Yukon or the Mackenzie Basin;	x	x	x	x	x	x	
4. a short wave trough moving southwestward through the eastern Northwest Territories;							x
5. a primary cold low in the region (or moving into the region)							
(a) 56°N to 76°N, 60°W to 98°W,	x						
(b) 63°N to 80°N, 70°W to 120°W,		x	x	x			
(c) 68°N to 78°N, 101°W to 138°W,					x		
(d) 66°N to 80°N, 130°W to 172°W,						x	
(e) 45°N to 50°N, 145°W to 150°W;							x
6. a secondary cold low in the region							
(a) of Southern Alberta,			x				
(b) 50°N to 60°N, 140°W to 160°W,				x			
(c) of the Gulf of Alaska;						x	
7. a flat ridge and warm air advection over British Columbia;	x	x	x	x	x	x	

500-MB INITIALLY THERE IS	TYPE I	II	III	IV	V	VI	VII
8. a long wave ridge west of 130°W which is either quasi-stationary or moving eastward;	x	x	x	x	x	x	
9. a pronounced ridge in region 100°W to 125°W;							x
10. a high in the region 30°N to 40°N, 130°W to 140°W and moving slowly westward;			x				
AFTER THE COLD AIR HAS COVERED ALBERTA THERE IS							
1. a northwesterly to northerly flow over Alberta;	x	x	x	x	x	x	x
2. a short wave trough which has moved southeastward through Alberta;	x	x	x	x	x	x	
3. a primary cold low in the region							
(a) 56°N to 76°N, 60°W to 98°W,	x						
(b) 63°N to 80°N, 70°W to 120°W,		x	x	x			
(c) 68°N to 78°N, 101°W to 138°W,					x		
(d) 66°N to 80°N, 130°W to 172°W,						x	
(e) 39°N to 41°N, 129°W to 131°W;							x
4. a secondary cold low in the region							
(a) 61°N to 64°N, 110°W to 118°W,			x				
(b) 53°N to 58°N, 110°W to 120°W.						x	
5. a drop in contour heights;	x	x	x	x	x	x	
6. little change in contour heights;							x
7. cold air advection over Alberta;	x	x	x	x	x	x	x
8. a long wave ridge (west of 125°W) over Alaska, the Yukon or the Mackenzie Basin;	x	x	x	x	x	x	

500-MB AFTER THE COLD AIR HAS COVERED ALBERTA THERE IS		TYPE I	II	III	IV	V	VI	VII
9.	a high in the region 54°N to 55°N, 119°W to 121°W, with a ridge extending northeastward from the high;							x
10.	a short wave trough which has moved southwestward through Alberta;							x
11.	a cold low in the region 39°N to 41°N, 129°W to 131°W.							x

Chapter 2

Discussion of Types

The Figures 2.1, .. etc .., 8.1 are examples of each type, showing the surface and 500-mb configurations, while the Figures 2.2, .. etc .., 8.2 are the corresponding cross-sections. The caption 6000 FT. VS. DEG. LAT. refers to the sloping lines in the upper left-hand corner of all cross-section diagrams, e.g. in Figure 2.2. These slopes are included as standards of reference and comparison for the plotted slopes of the actual frontal surfaces. Figures 2.3, .. etc .., 8.3 through Figures 2.5, .. etc .., 7.5 are used in forecasting. This will be described in detail in Chapter 3.

The differences among types is due to either one unique characteristic or a combination of characteristics. This is illustrated in Figures 2.1, .. etc .., 8.1, and Figures 2.3, .. etc .., 8.3.

The main surface synoptic features of Type I consist of a large arctic high building southeastward through Alaska, the Yukon, or the Mackenzie Basin; a low moving southeastward through Northern Alberta; and a high moving southward through the Western United States, in particular Washington, Montana, Oregon, Idaho, and Nevada. At the 500-mb level, Type I is characterized by a cold low northwest of Hudson Bay with a short wave trough moving southeastward through Alaska, the Yukon or the Mackenzie Basin.

Type II is markedly different in that only a frontal wave moves southeastward through the Western Prairies while the low center itself moves eastward, along a track through the southern parts of the Northwest Territories. Furthermore, the high pressure system in

the Pacific and Northwestern States is very weak or altogether absent. At the 500-mb level, the dominant feature is a pronounced ridge lying over Alaska.

Type III differs from the first two by its well-developed binary system of surface lows (see Figures 4.1 and 4.3). At the 500-mb level there is a corresponding system of two cold lows with a primary center situated over the most northerly islands of the Arctic Archipelago and a secondary center emerging from Southern Alaska and tracking east-southeastward.

Type IV is distinguished by the surface configuration of a deep secondary frontal low north of Lake Athabasca. At the 500-mb level there is again a binary cold low system, but the primary center is west-northwest of Baffin Island and the secondary is moving southeastward from the Gulf of Alaska.

Type V differs, at the surface, from the other types in that the low moves east-southeastward through Central Alberta, while a secondary high moves southeastward through Northern Manitoba. At the 500-mb level the cold low moves southward from the northern reaches of the Arctic Archipelago to the vicinity of Cambridge Bay.

The distinctive features of Type VI are best seen at the 500-mb level. Here the cold low is located northwest of Inuvik and a short wave trough or secondary cold low is moving east-southeastward from the Gulf of Alaska.

Type VII, if it may be classified as such, is unique in that it is an omega block situation. It differs markedly from the other types as is readily seen by inspection of Figures 8.1, 8.3, 8.4 and 8.5.

Comparison of the types found in this study to those listed in Synoptic Weather Types Of North America[1] are as follows:

Type I	Bs Winter
Type II	Eh Winter
Type III	F Winter
Type IV	Bn Winter
Type V	Cl Winter
Type VI	Bs and Bn Fall, B-A Winter and Early Spring

There was no listing which corresponded to Type VII. As mentioned earlier, this is an omega block condition and relatively rare. Although there were only a few cases for some of the types found, the matching of these types to those mentioned in the above reference would indicate that they are more common than the period studied would indicate.

The remainder of this chapter consists of sets of figures describing each type.

---

[1] P. E. Ruch (Ed.), " Synoptic Weather Types Of North America ", Meteorology Department, California Institute Of Technology, No.1855, Pasadena, California, 1943, 161 pp.

TYPE I

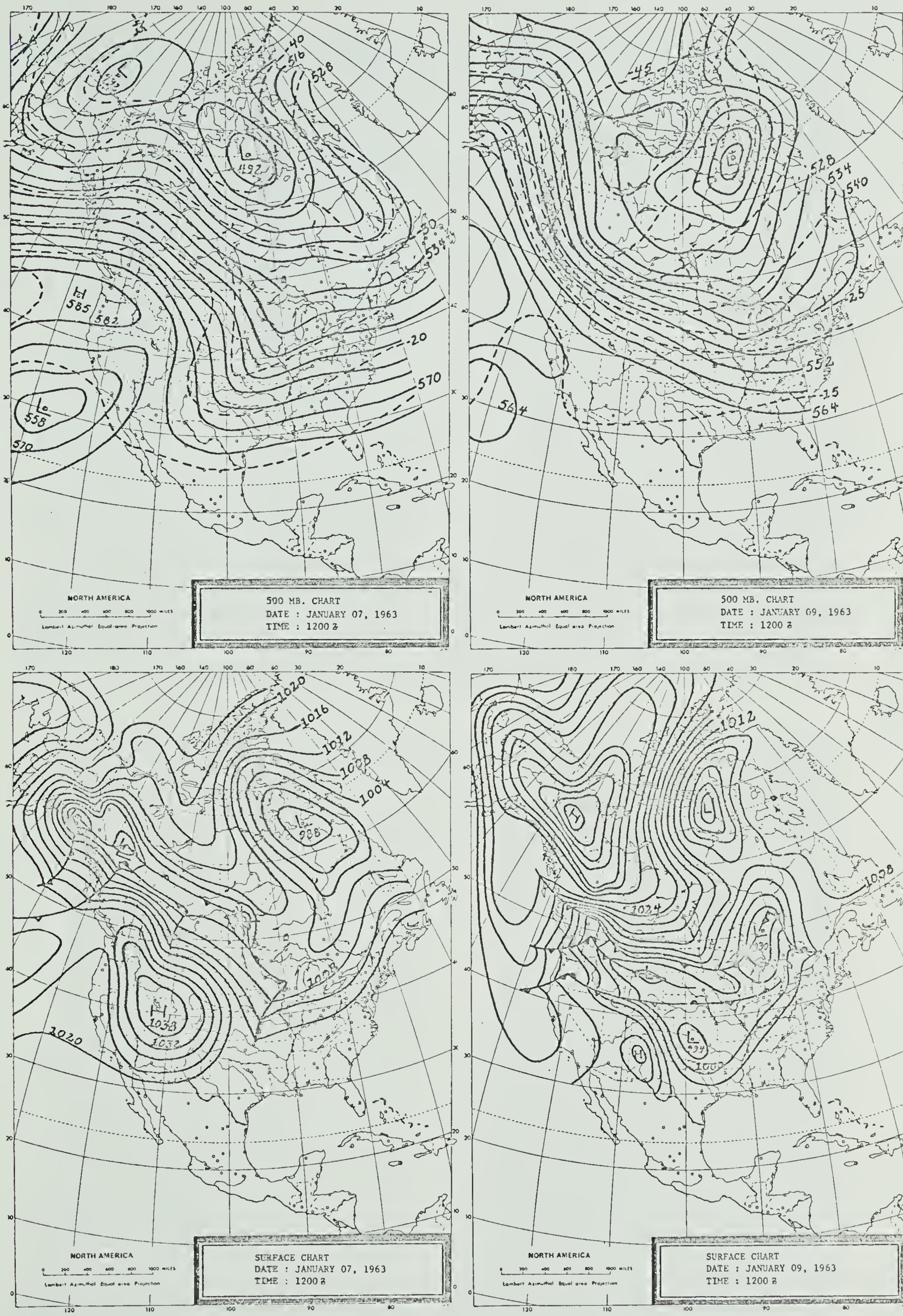

NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. CHART
DATE : JANUARY 07, 1963
TIME : 1200 Z
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. CHART
DATE : JANUARY 09, 1963
TIME : 1200 Z
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE CHART
DATE : JANUARY 07, 1963
TIME : 1200 Z
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE CHART
DATE : JANUARY 09, 1963
TIME : 1200 Z

FIGURE 2.1

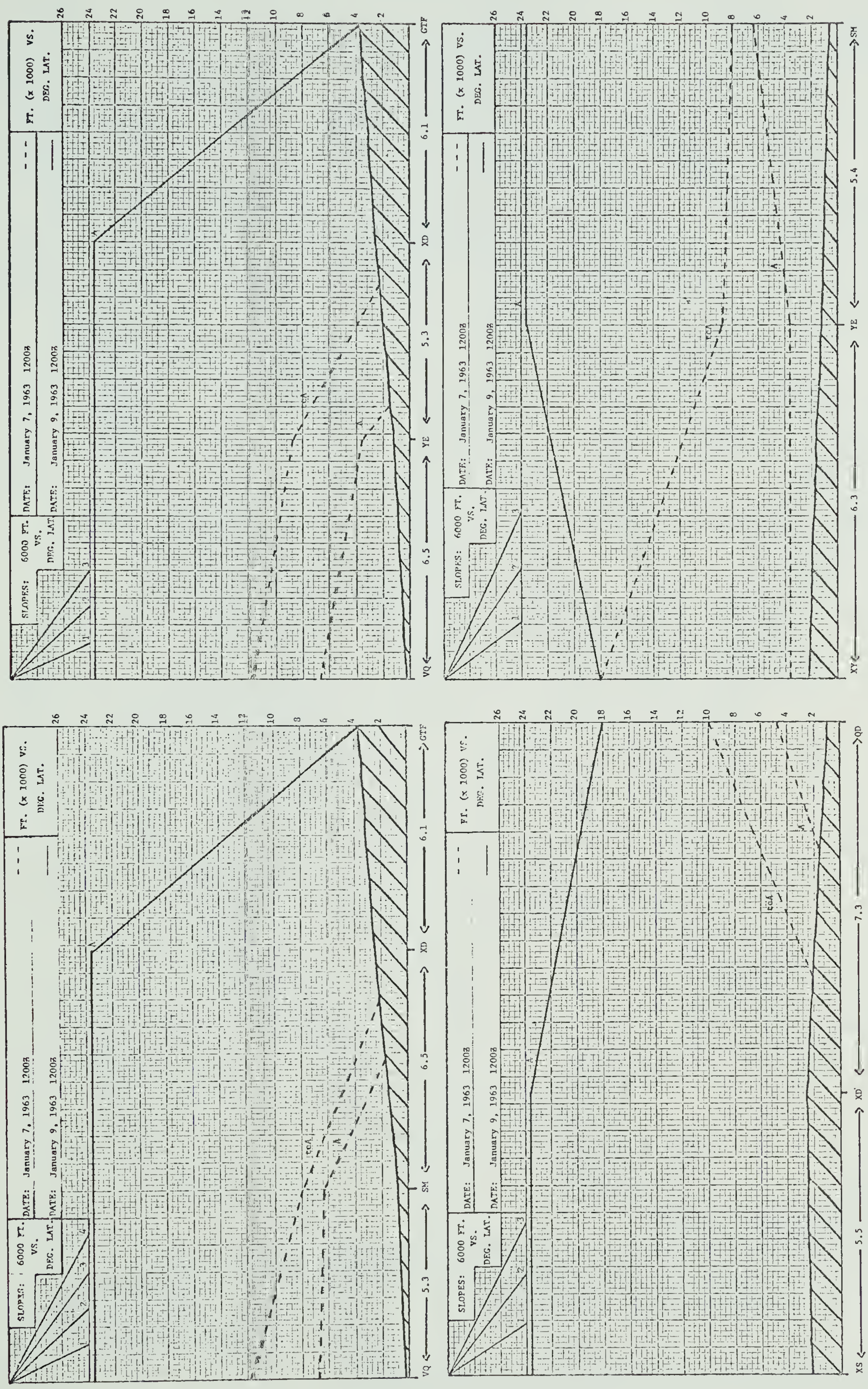
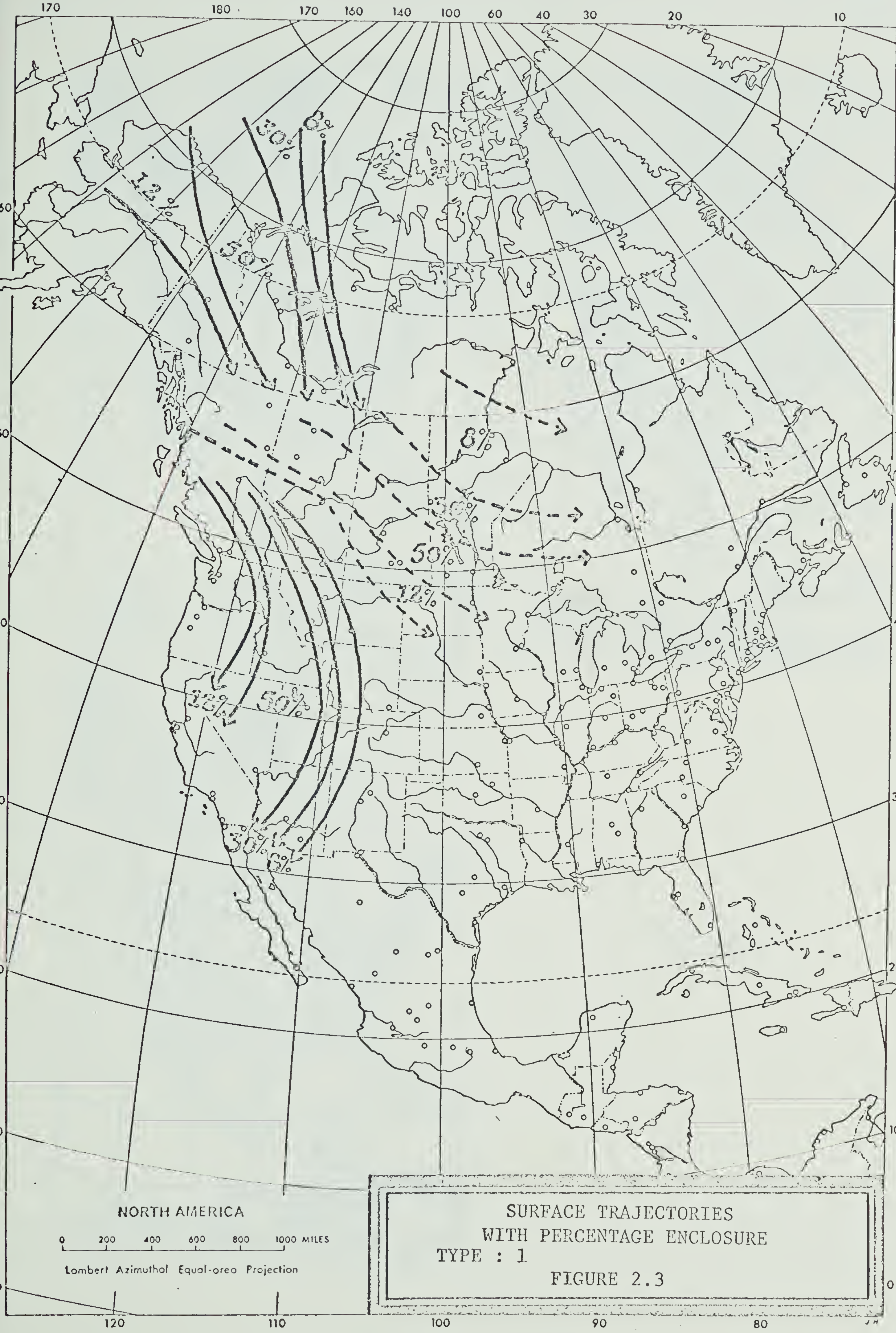

SLOPES: 6000 FT. VS. DEG. LAT.
DATE: January 7, 1963 1200Z
DATE: January 9, 1963 1200Z
FT. (x 1000) VS. DEG. LAT.
VQ
SM
XD
CTF
YE
XY
XS
QD
5.3
6.5
6.1
6.3
5.4
5.5
7.3

FIGURE 2.2



SURFACE TRAJECTORIES
WITH PERCENTAGE ENCLOSURE
TYPE : 1

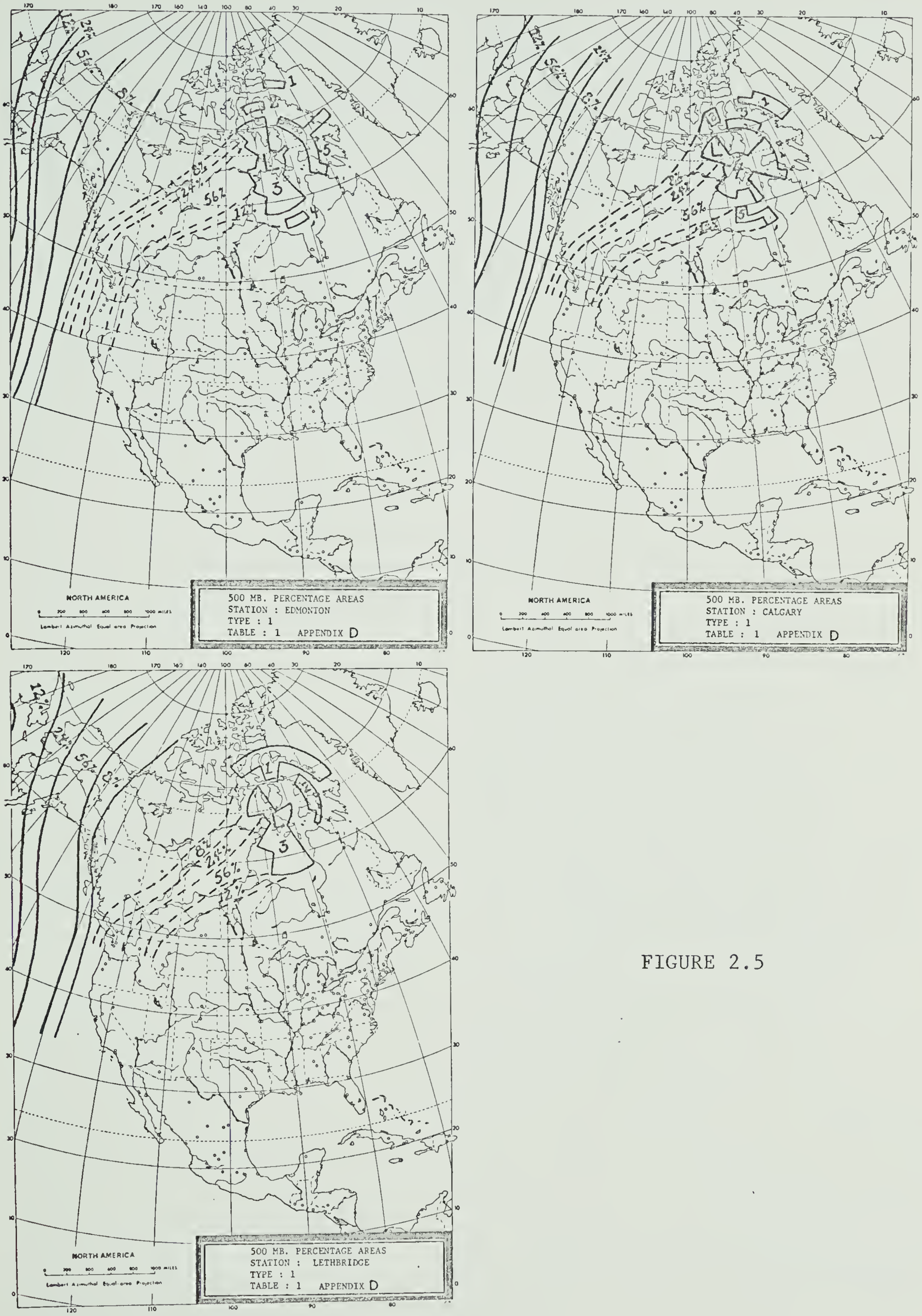
FIGURE 2.3


NORTH AMERICA
SURFACE PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 1
TABLE : 1 APPENDIX C


NORTH AMERICA
SURFACE PERCENTAGE AREAS
STATION : CALGARY
TYPE : 1
TABLE : 1 APPENDIX C


NORTH AMERICA
SURFACE PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 1
TABLE : 1 APPENDIX C

FIGURE 2.4



NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 1
TABLE : 1 APPENDIX D
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : CALGARY
TYPE : 1
TABLE : 1 APPENDIX D
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 1
TABLE : 1 APPENDIX D

FIGURE 2.5

TYPE II

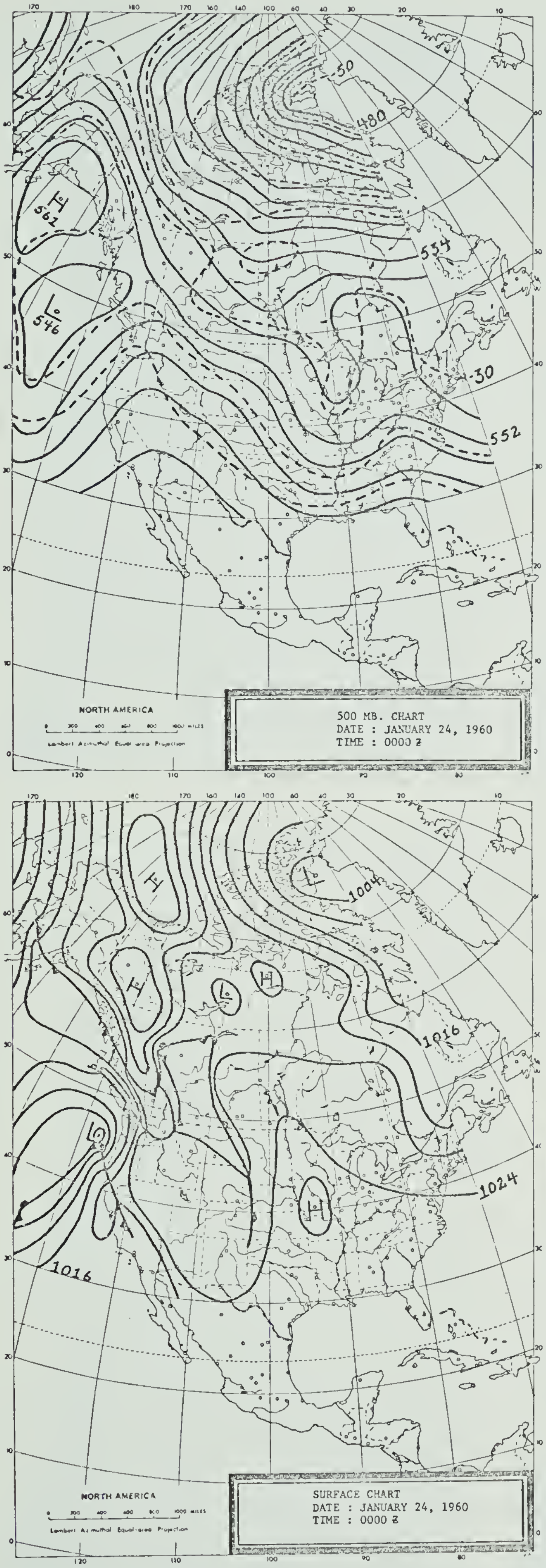

500 MB. CHART
DATE : JANUARY 24, 1960
TIME : 0000 Z
500 MB. CHART
DATE : JANUARY 25, 1960
TIME : 1200 Z
SURFACE CHART
DATE : JANUARY 24, 1960
TIME : 0000 Z
SURFACE CHART
DATE : JANUARY 25, 1960
TIME : 1200 Z
NORTH AMERICA
Lambert Azimuthal Equal-area Projection

FIGURE 3.1

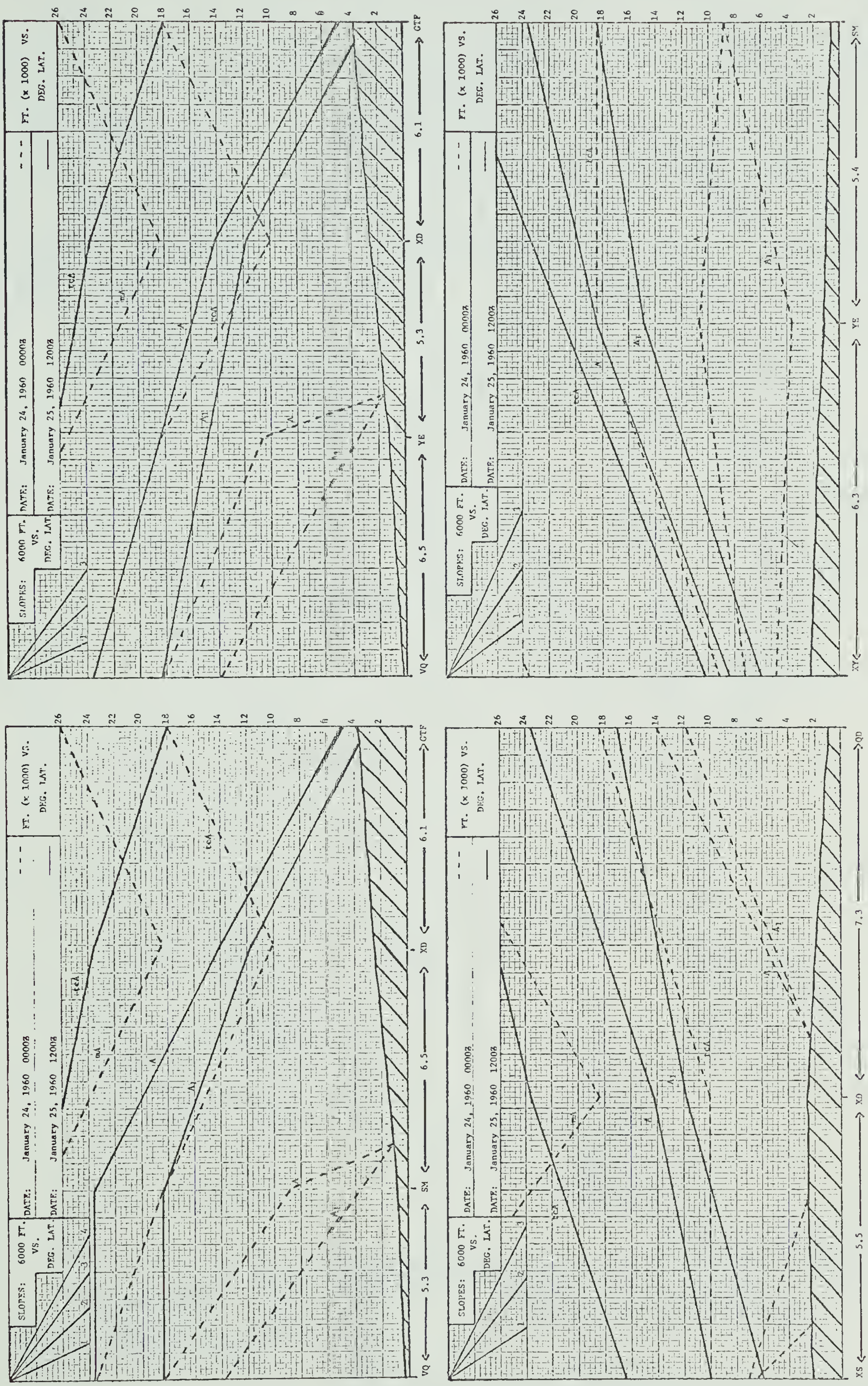
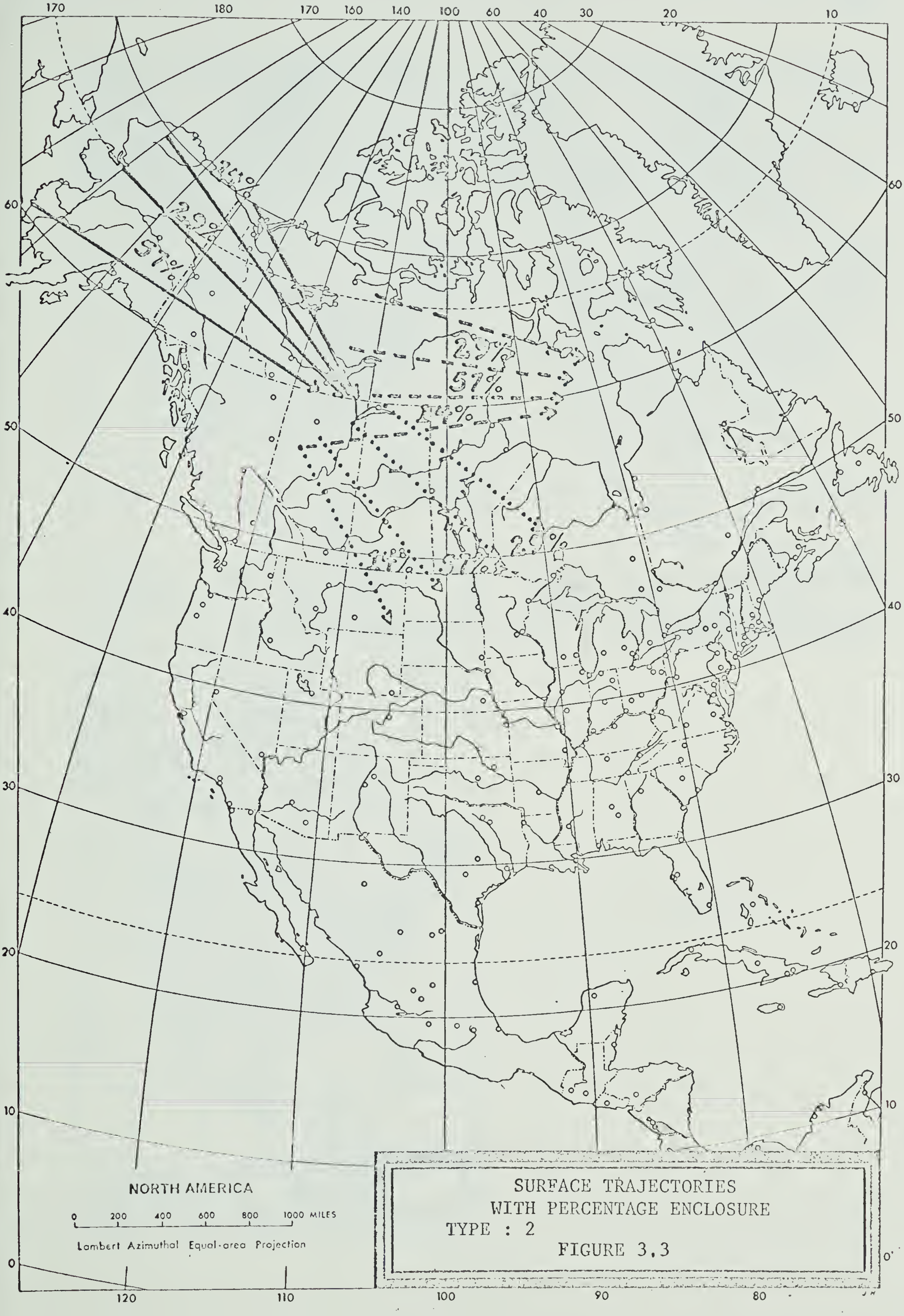

SLOPES:
6000 FT. VS. DEG. LAT.
DATE: January 24, 1960 0000Z
DATE: January 25, 1960 1200Z
FT. (x 1000) VS. DEG. LAT.
VQ
XD
YE
GTF
SM
XS
XY
QD

FIGURE 3.2



SURFACE TRAJECTORIES
WITH PERCENTAGE ENCLOSURE
TYPE : 2
FIGURE 3.3


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 2
TABLE ; 2 APPENDIX C


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : CALGARY
TYPE : 2
TABLE : 2 APPENDIX C


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 2
TABLE ; 2 APPENDIX C

FIGURE 3.4


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 2
TABLE ; 2 APPENDIX D
29%
57%
14%


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : CALGARY
TYPE : 2
TABLE : 2 APPENDIX D
29%
57%
14%

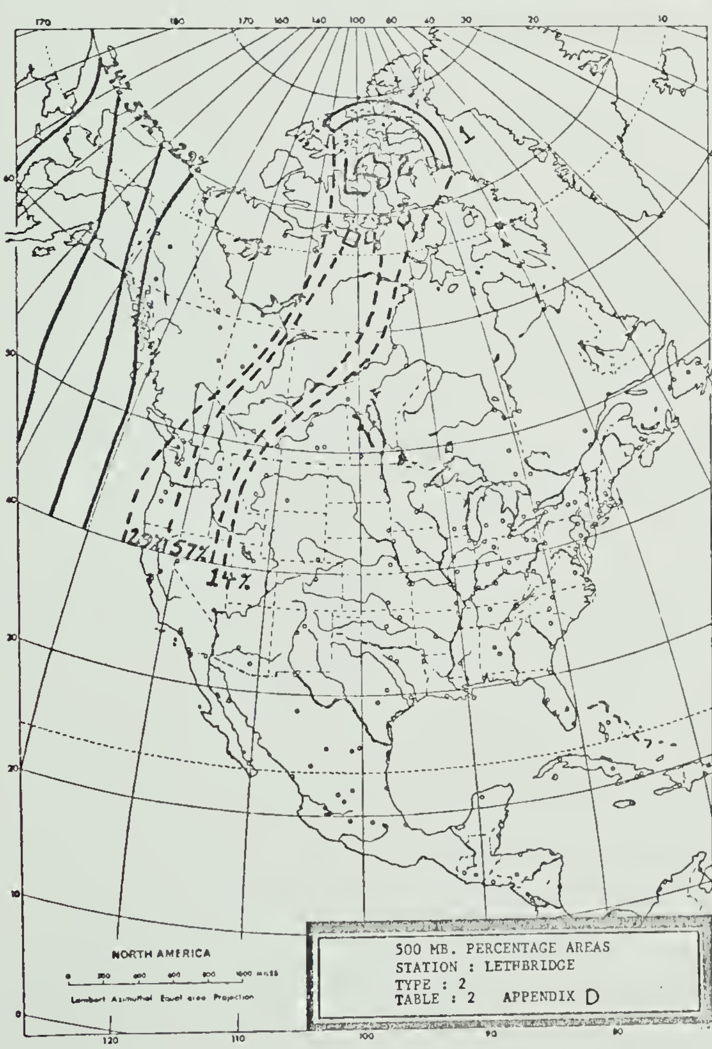

NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 2
TABLE : 2 APPENDIX D
29%
57%
14%

FIGURE 3.5

TYPE III

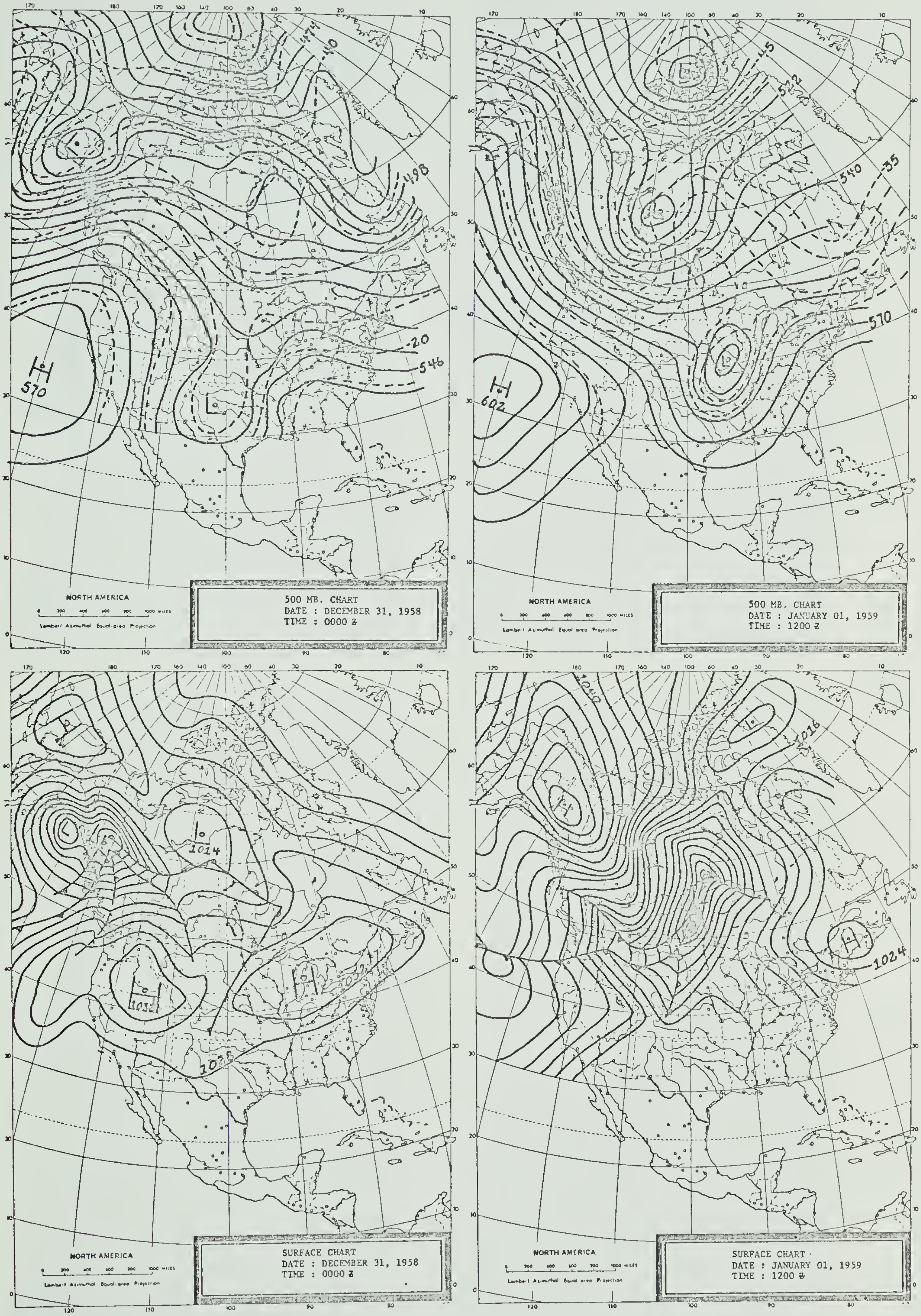

NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. CHART
DATE : DECEMBER 31, 1958
TIME : 0000 Z
474
40
498
-20
546
570
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. CHART
DATE : JANUARY 01, 1959
TIME : 1200 Z
-45
522
540
-35
570
602
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE CHART
DATE : DECEMBER 31, 1958
TIME : 0000 Z
1014
1035
1026
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE CHART
DATE : JANUARY 01, 1959
TIME : 1200 Z
1016
1024

FIGURE 4.1

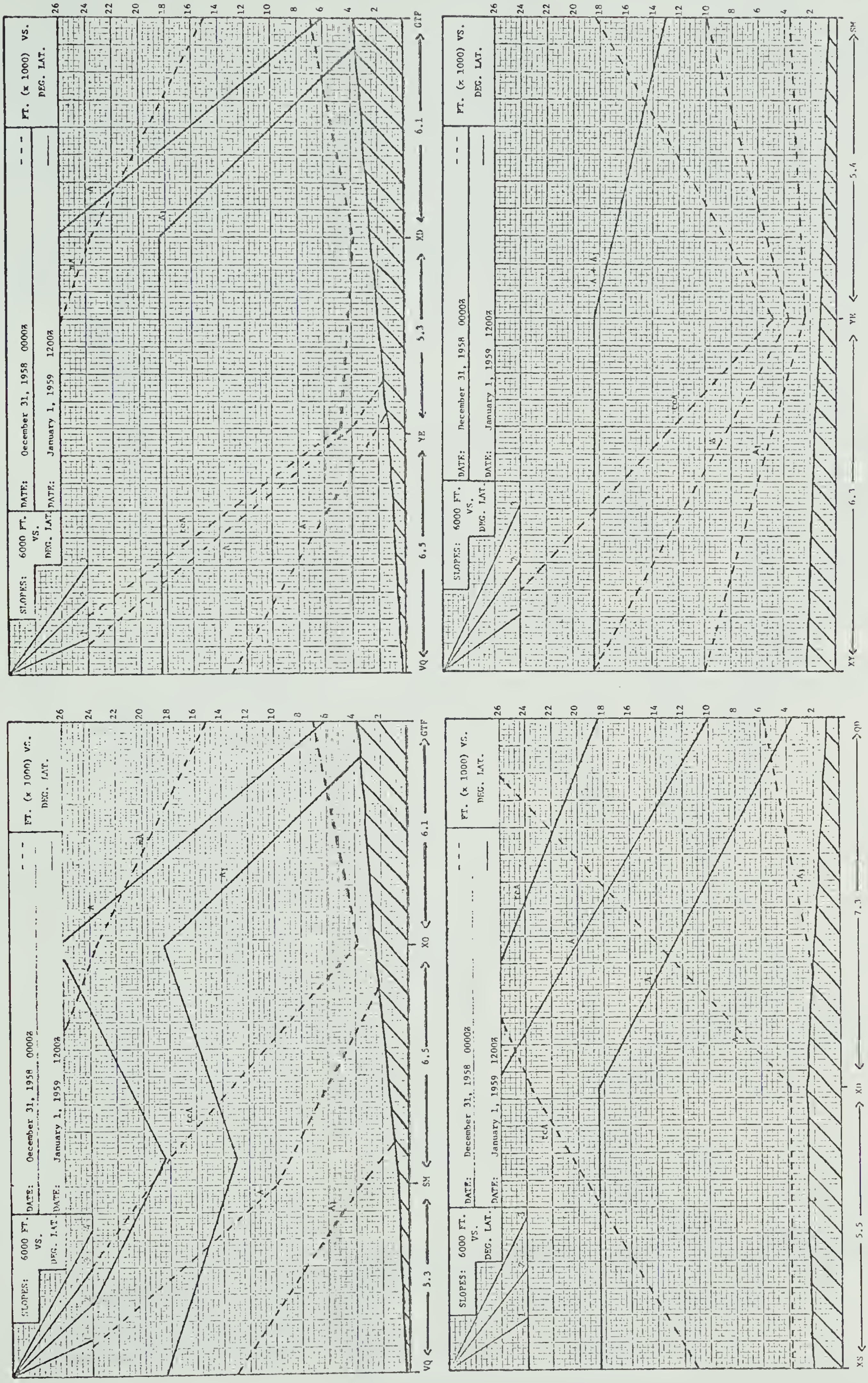
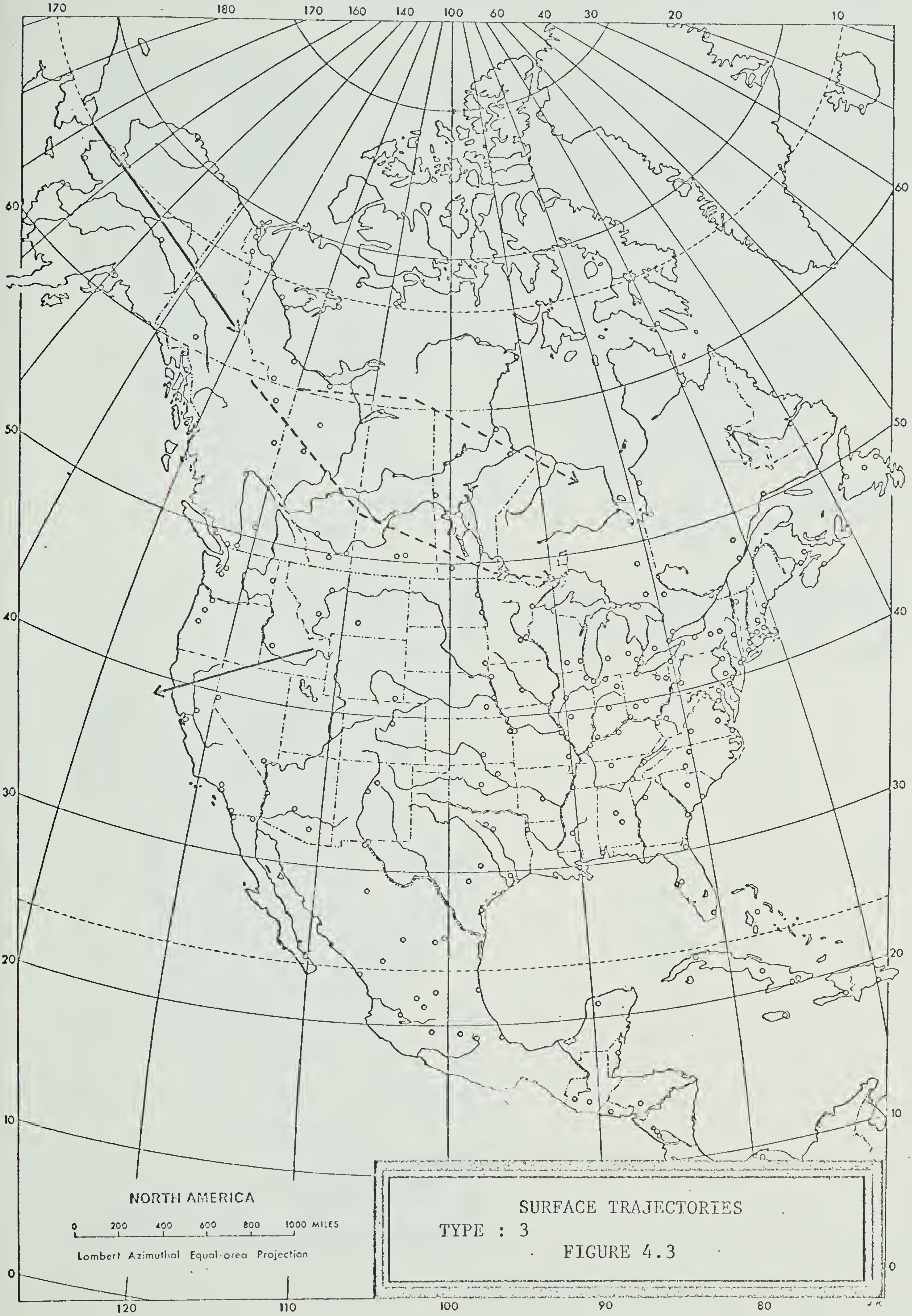

SLOPES: 6000 FT. VS. DEG. LAT.
DATE: December 31, 1958 0000Z
DATE: January 1, 1959 1200Z
FT. (x 1000) VS. DEG. LAT.

FIGURE 4.2



SURFACE TRAJECTORIES

TYPE : 3

FIGURE 4.3

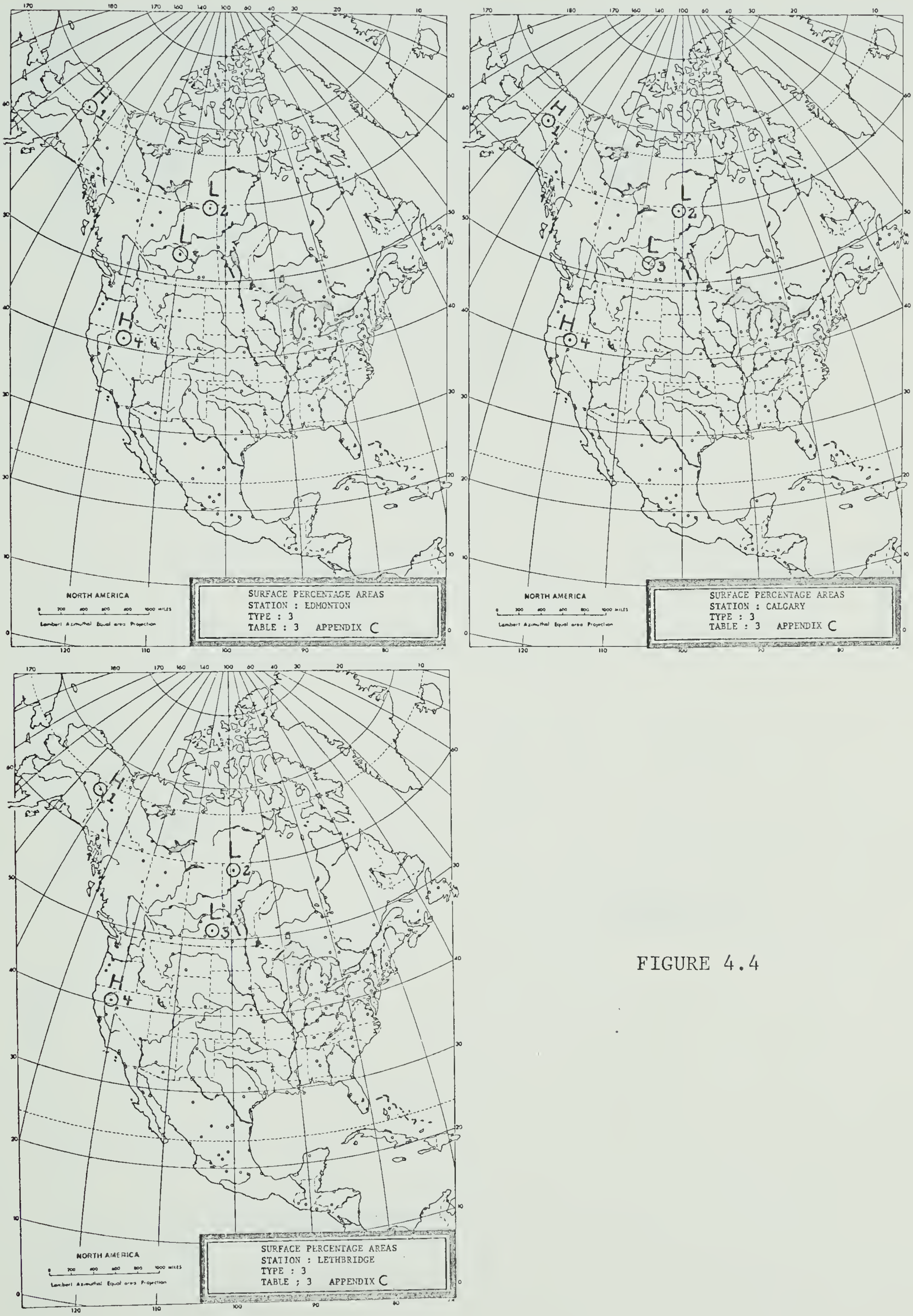
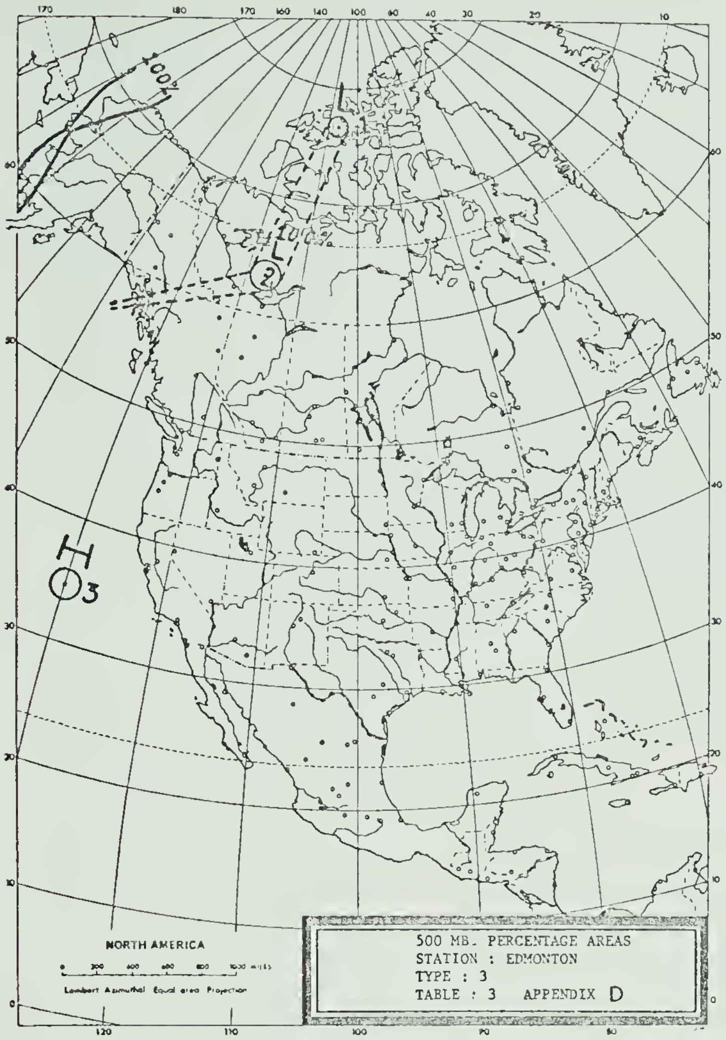

NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 3
TABLE : 3 APPENDIX C
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : CALGARY
TYPE : 3
TABLE : 3 APPENDIX C
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 3
TABLE ; 3 APPENDIX C

FIGURE 4.4


100%
100%
H
3
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 3
TABLE : 3 APPENDIX D


100%
100%
H
3
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : CALGARY
TYPE : 3
TABLE : 3 APPENDIX D

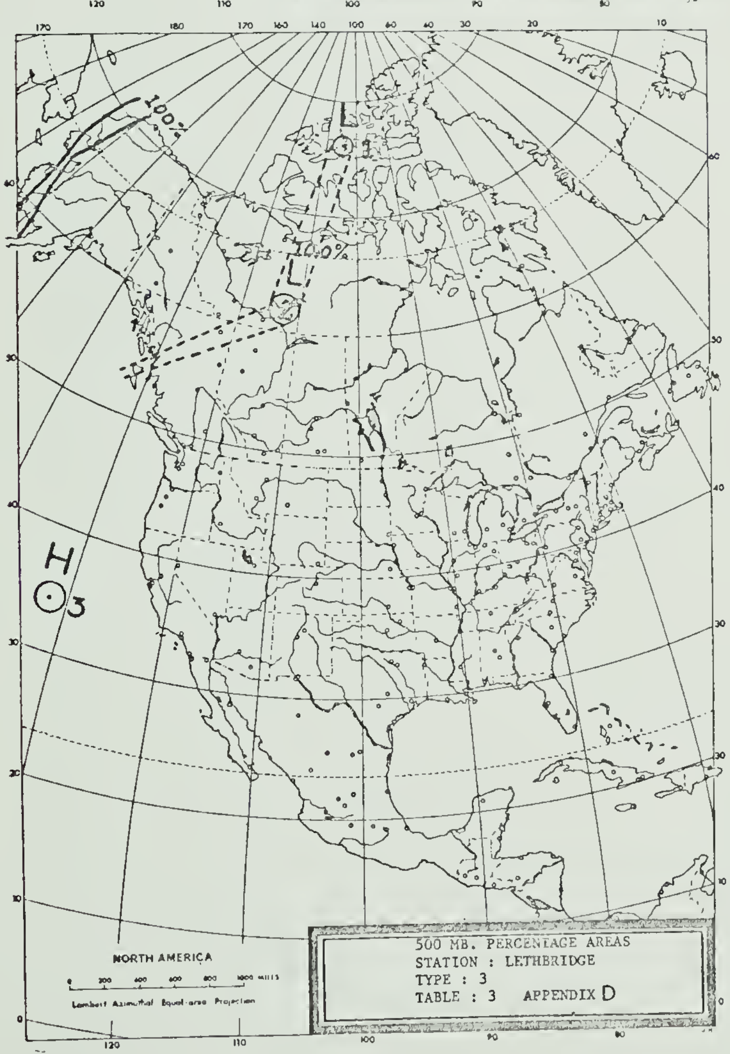

100%
100%
H
3
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 3
TABLE : 3 APPENDIX D

FIGURE 4.5

TYPE IV

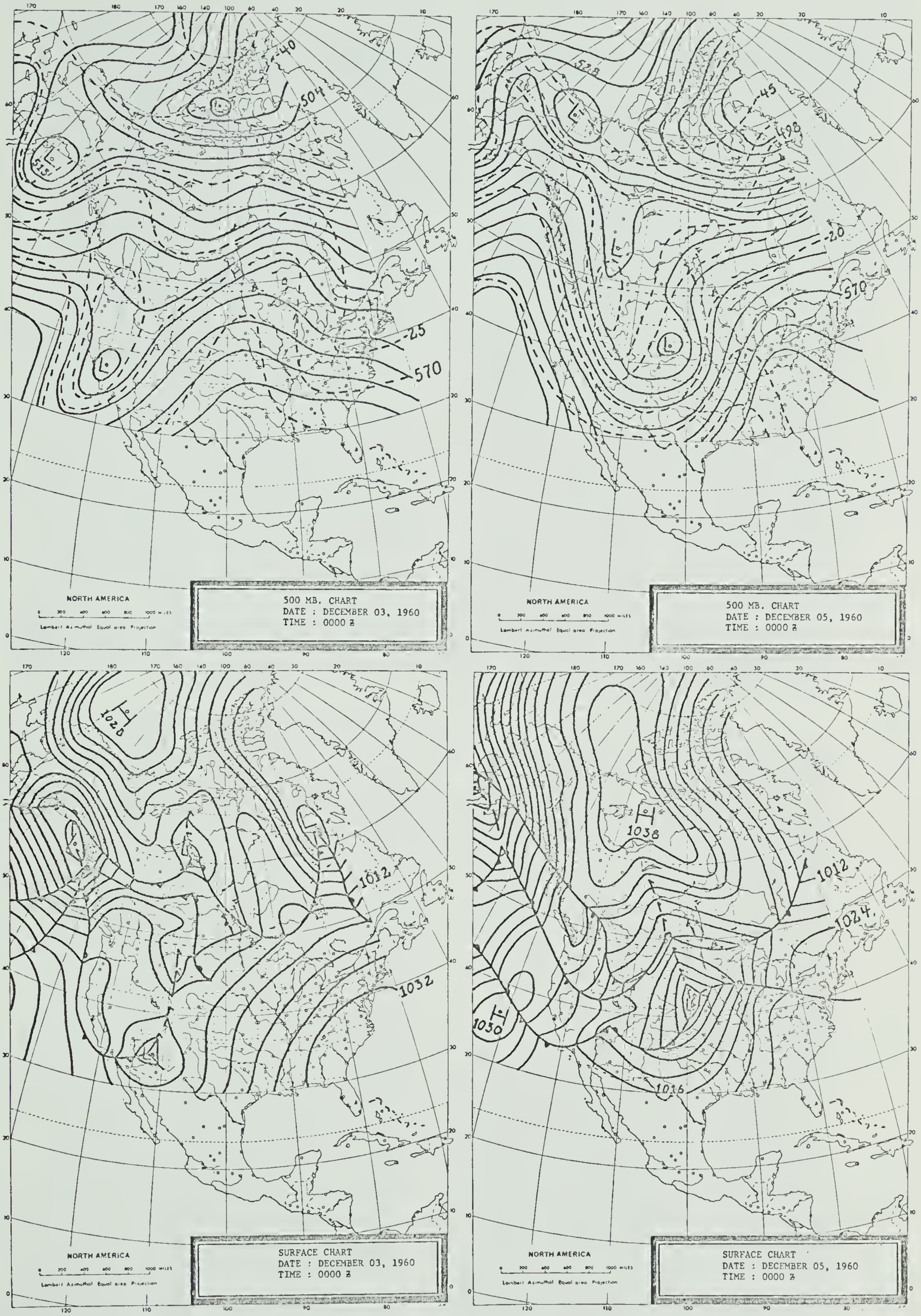

NORTH AMERICA
Lambert Azimuthal Equal area Projection
500 MB. CHART
DATE : DECEMBER 03, 1960
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal area Projection
500 MB. CHART
DATE : DECEMBER 05, 1960
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal area Projection
SURFACE CHART
DATE : DECEMBER 03, 1960
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal area Projection
SURFACE CHART
DATE : DECEMBER 05, 1960
TIME : 0000 Z

FIGURE 5.1

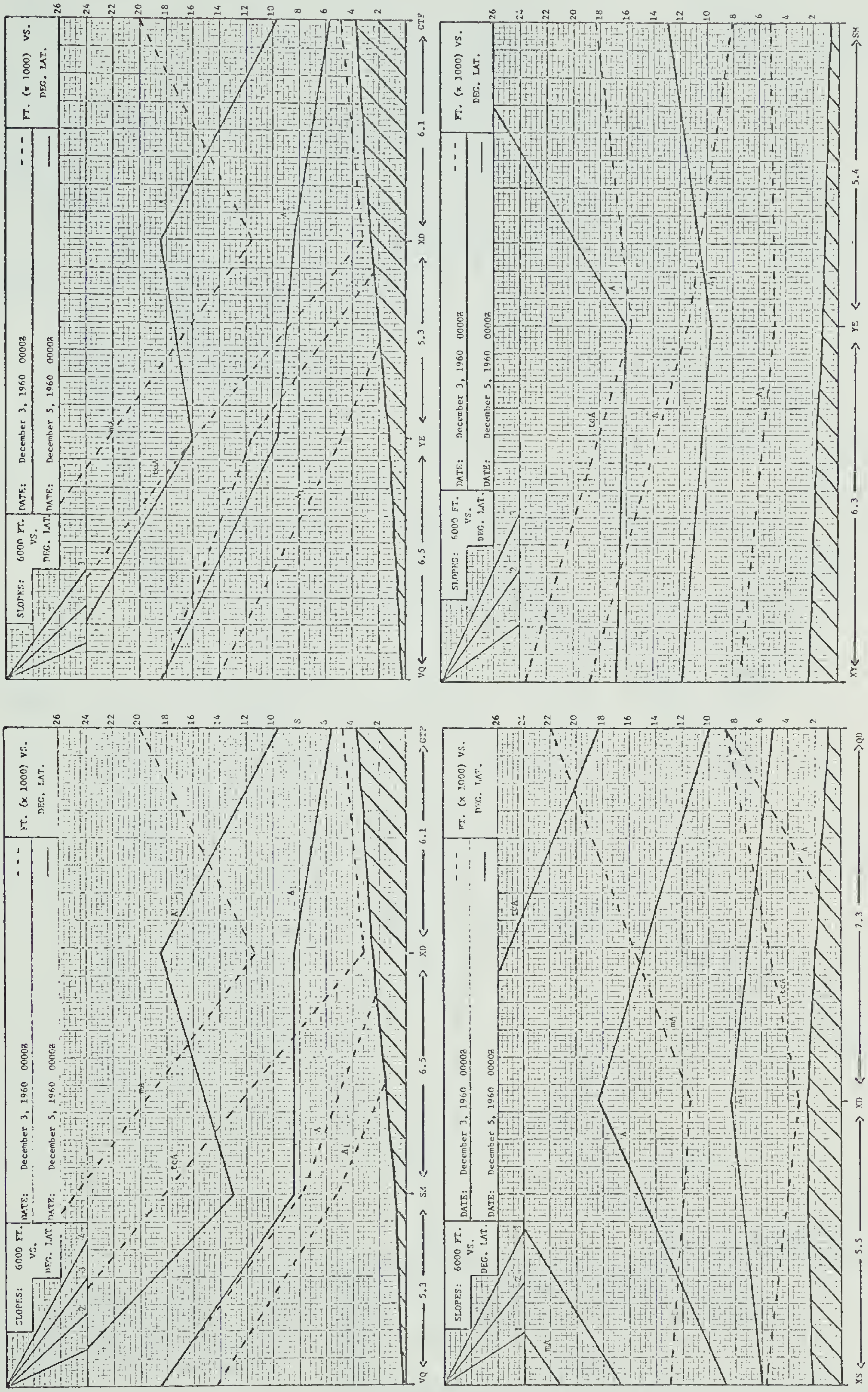
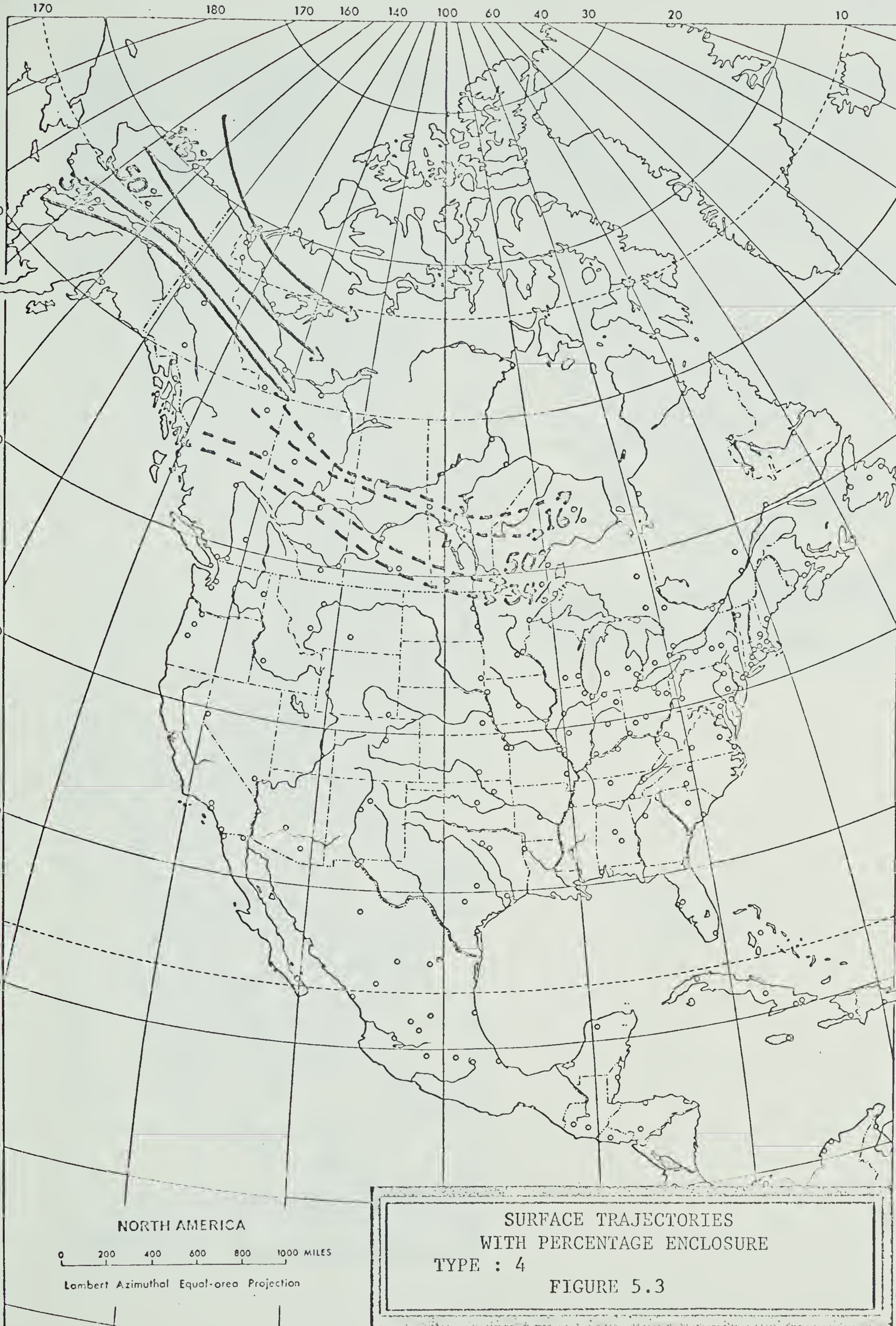

SLOPES: 6000 FT. VS. DEG. LAT.
DATE: December 3, 1960 0000Z
DATE: December 5, 1960 0000Z
FT. (x 1000) VS. DEG. LAT.

FIGURE 5.2



SURFACE TRAJECTORIES
WITH PERCENTAGE ENCLOSURE
TYPE : 4
FIGURE 5.3


NORTH AMERICA
Lambert Azimuthal Equal area Projection
SURFACE PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 4
TABLE : 4 APPENDIX C


NORTH AMERICA
Lambert Azimuthal Equal area Projection
SURFACE PERCENTAGE AREAS
STATION : CALGARY
TYPE : 4
TABLE : 4 APPENDIX C


NORTH AMERICA
Lambert Azimuthal Equal area Projection
SURFACE PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 4
TABLE : 4 APPENDIX C

FIGURE 5.4


NORTH AMERICA
500 MB. PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 4
TABLE : 4 APPENDIX D


NORTH AMERICA
500 MB. PERCENTAGE AREAS
STATION : CALGARY
TYPE : 4
TABLE : 4 APPENDIX D


NORTH AMERICA
500 MB. PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 4
TABLE : 4 APPENDIX D

FIGURE 5.5

TYPE V

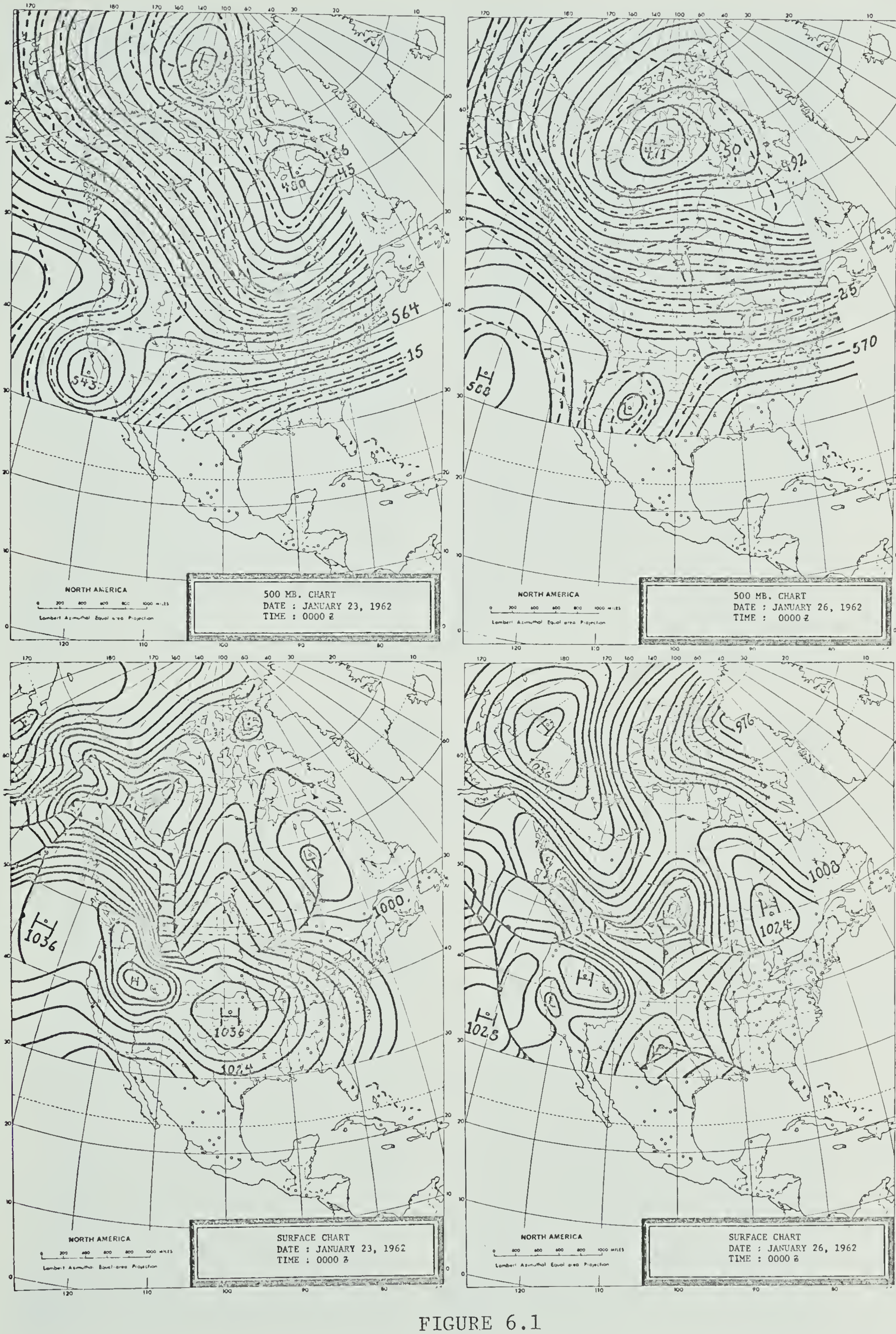

NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. CHART
DATE : JANUARY 23, 1962
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. CHART
DATE : JANUARY 26, 1962
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE CHART
DATE : JANUARY 23, 1962
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE CHART
DATE : JANUARY 26, 1962
TIME : 0000 Z

FIGURE 6.1

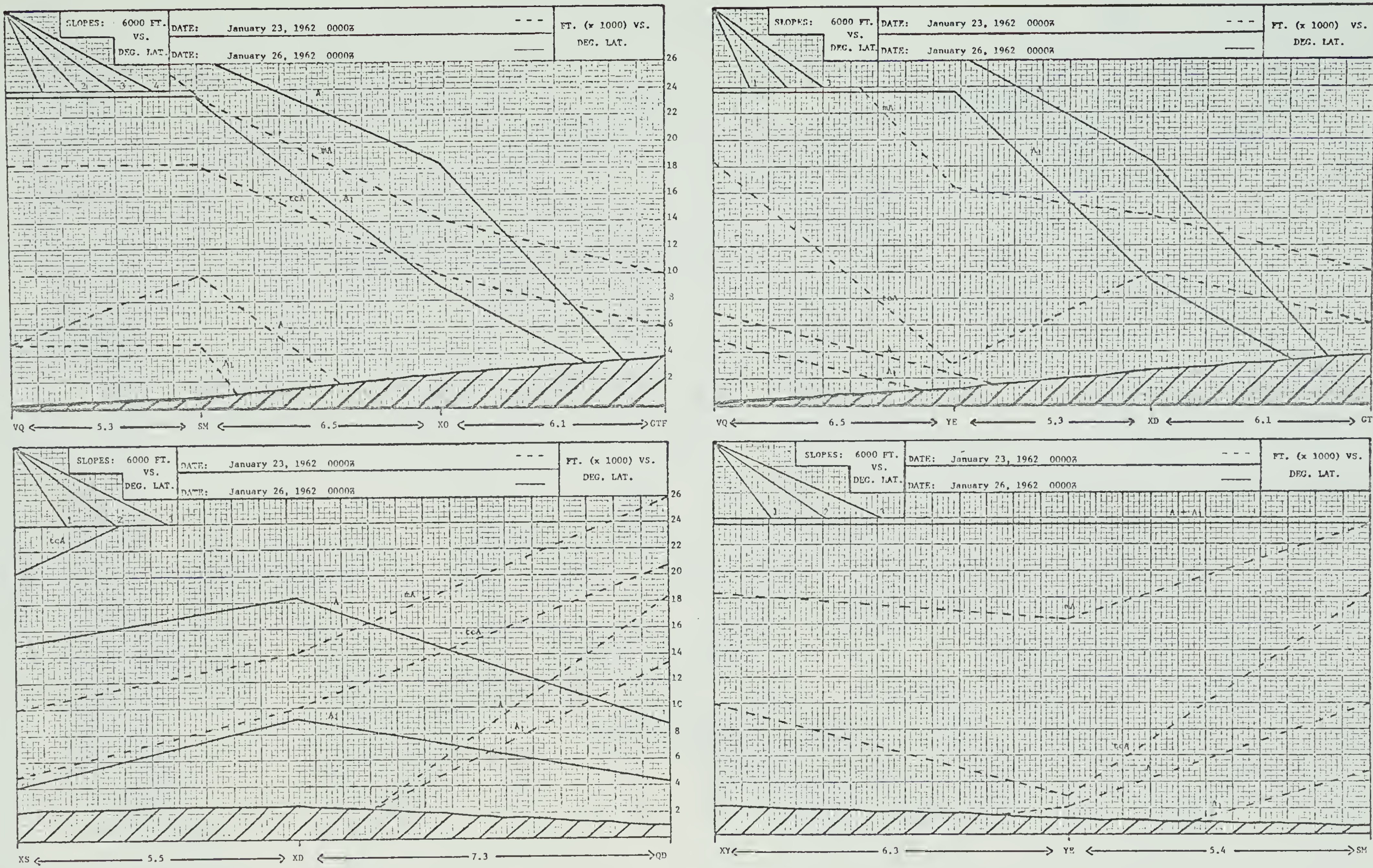
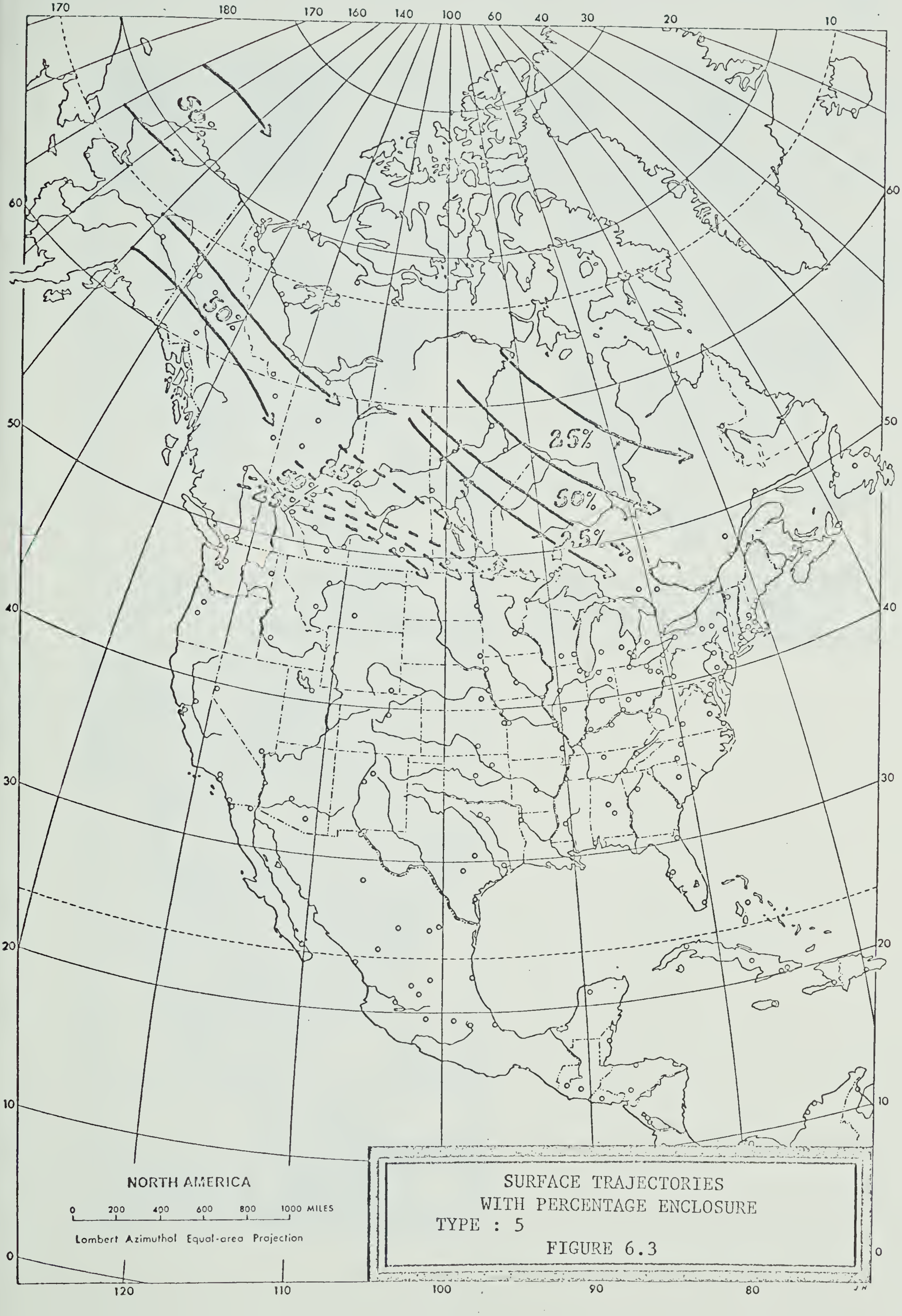

SLOPES: 6000 FT. VS. DEG. LAT.
DATE: January 23, 1962 0000Z
DATE: January 26, 1962 0000Z
FT. (x 1000) VS. DEG. LAT.
VQ ← 5.3 → SM ← 6.5 → XO ← 6.1 → GTF
VQ ← 6.5 → YE ← 5.3 → XD ← 6.1 → GTF
XS ← 5.5 → XD ← 7.3 → QD
XY ← 6.3 → YE ← 5.4 → SM

FIGURE 6.2



SURFACE TRAJECTORIES
WITH PERCENTAGE ENCLOSURE
TYPE : 5

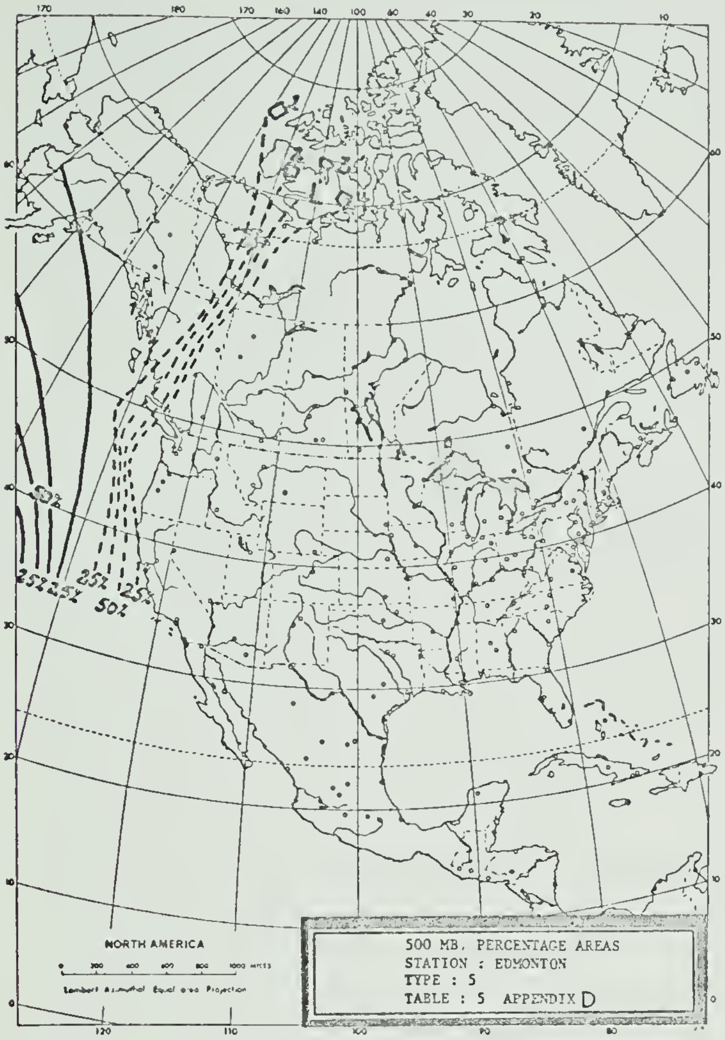
FIGURE 6.3

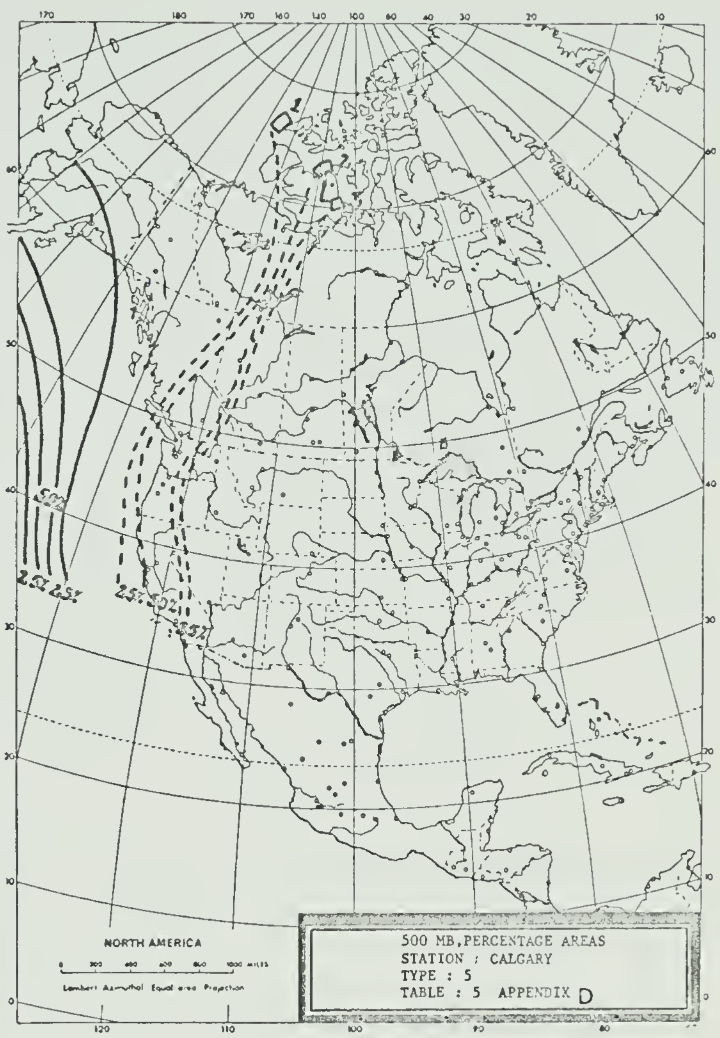

NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 5
TABLE : 5 APPENDIX C


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : CALGARY
TYPE : 5
TABLE : 5 APPENDIX C


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 5
TABLE : 5 APPENDIX C

FIGURE 6.4


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 5
TABLE : 5 APPENDIX D
50%
25%
25%
25%
25%
50%


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : CALGARY
TYPE : 5
TABLE : 5 APPENDIX D
50%
25%
25%
25%
50%
25%

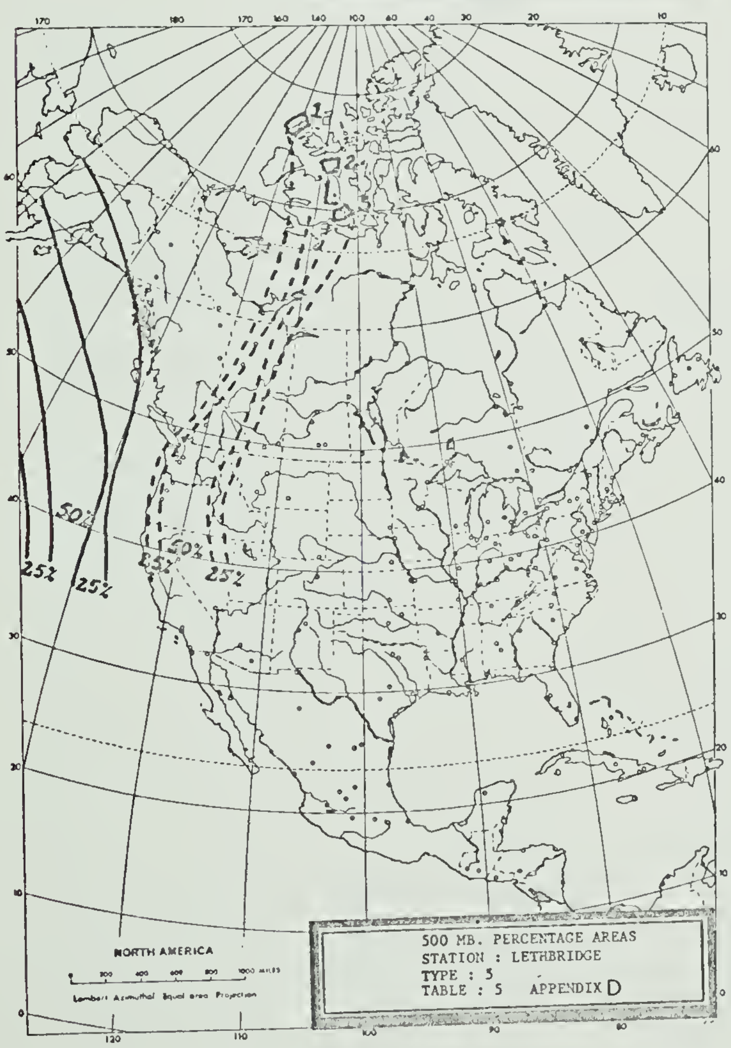

NORTH AMERICA
Lambert Azimuthal Equal-area Projection
500 MB. PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 5
TABLE : 5 APPENDIX D
50%
25%
25%
50%
25%
25%

FIGURE 6.5

TYPE VI

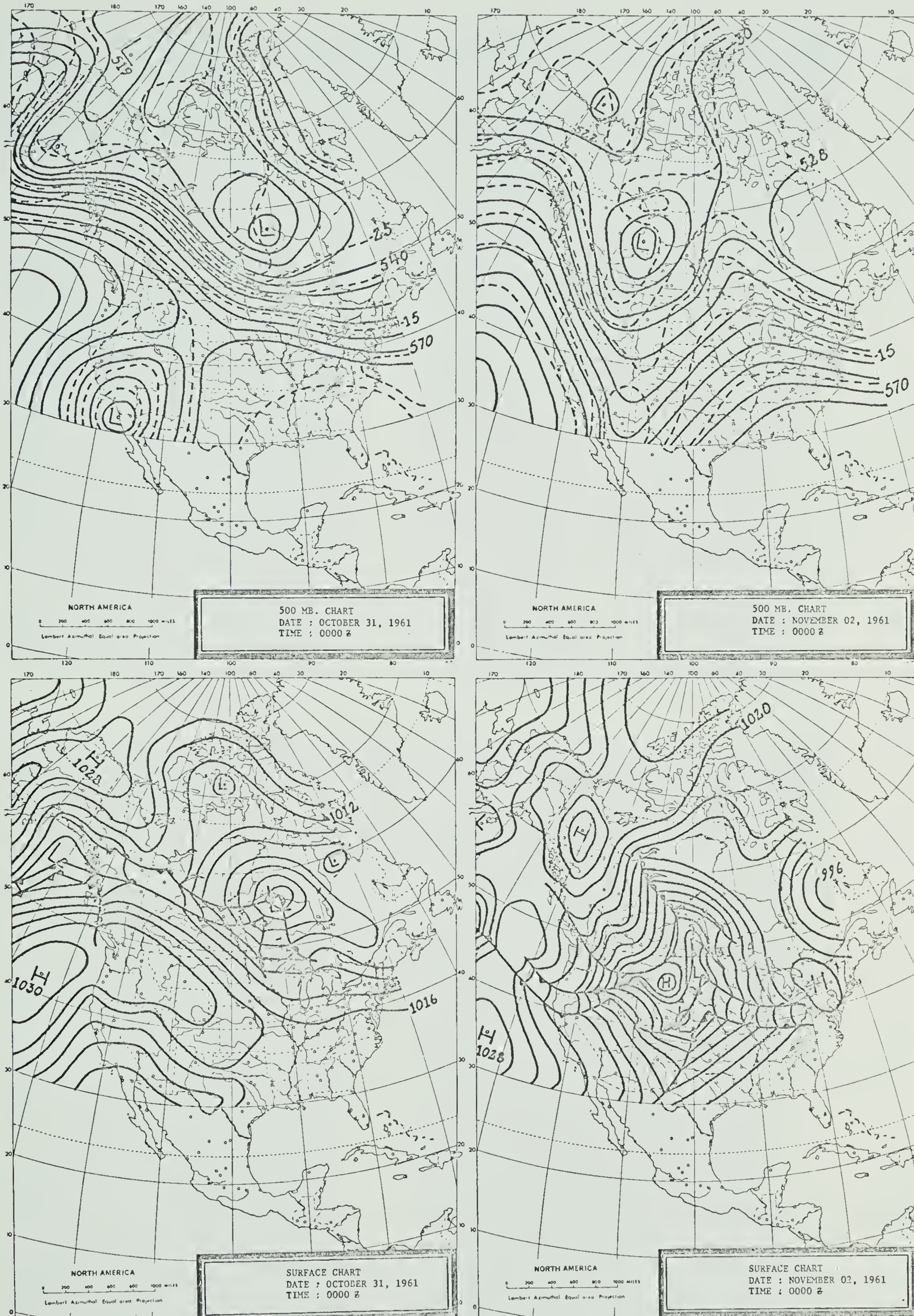
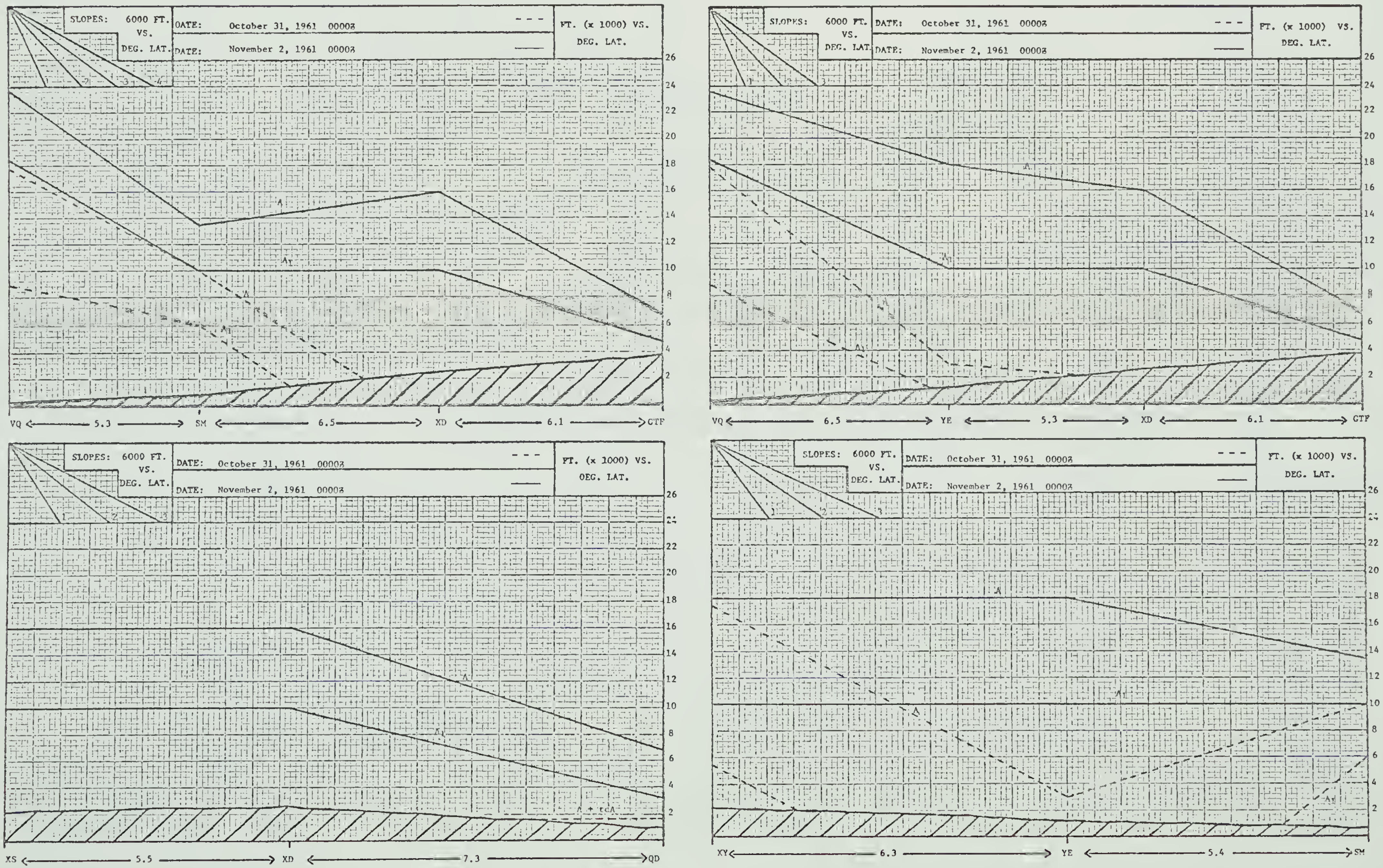
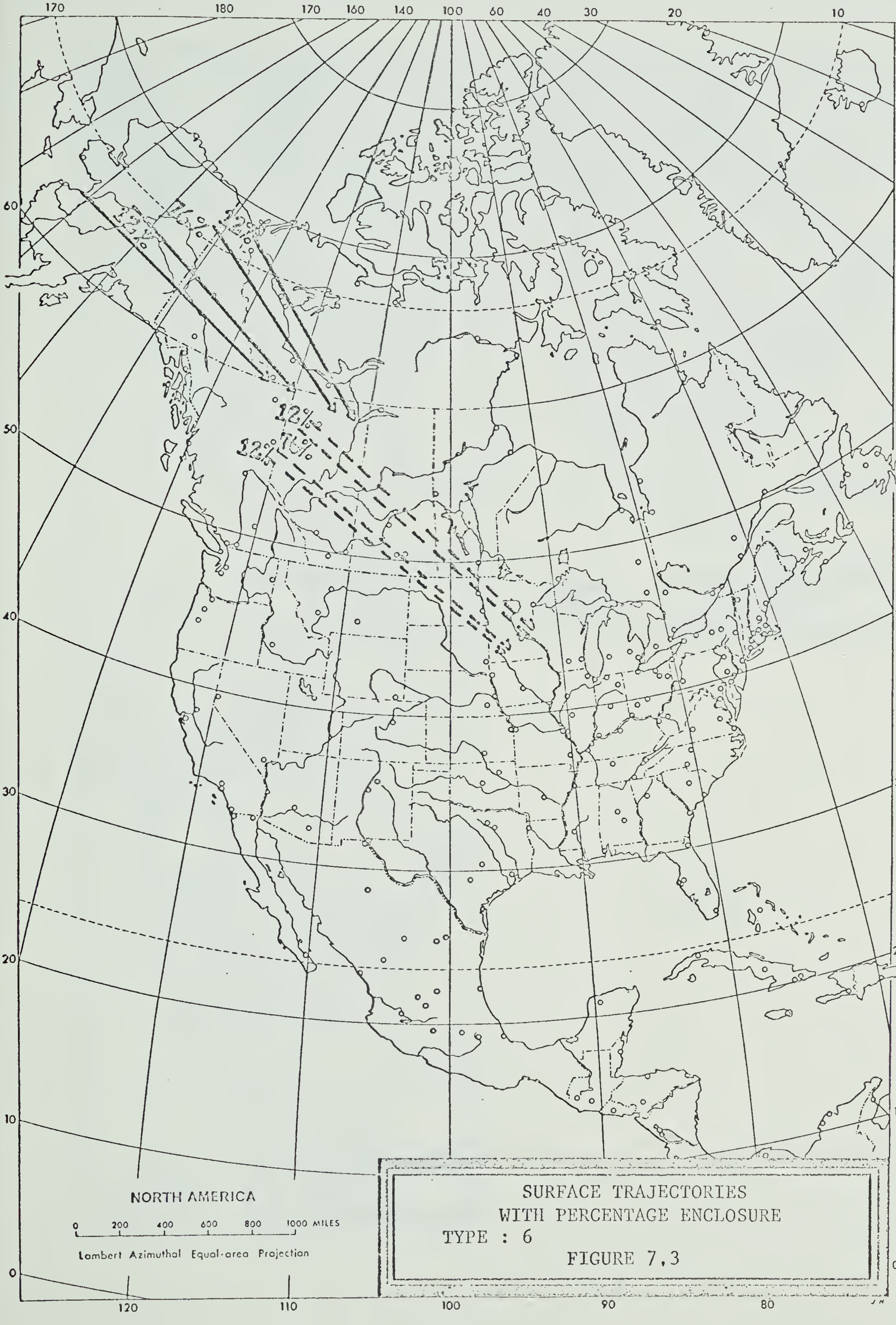

NORTH AMERICA
Lambert Azimuthal Equal area Projection
500 MB. CHART
DATE : OCTOBER 31, 1961
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal area Projection
500 MB. CHART
DATE : NOVEMBER 02, 1961
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal area Projection
SURFACE CHART
DATE : OCTOBER 31, 1961
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal area Projection
SURFACE CHART
DATE : NOVEMBER 02, 1961
TIME : 0000 Z

FIGURE 7.1



SLOPES: 6000 FT. VS. DEG. LAT.
DATE: October 31, 1961 0000Z
DATE: November 2, 1961 0000Z
FT. (x 1000) VS. DEG. LAT.
VQ 5.3 SM 6.5 XD 6.1 CTF
VQ 6.5 YE 5.3 XD 6.1 CTF
XS 5.5 XD 7.3 QD
XY 6.3 YE 5.4 SM

FIGURE 7.2



SURFACE TRAJECTORIES
WITH PERCENTAGE ENCLOSURE
TYPE : 6
FIGURE 7.3


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 6
TABLE : 6 APPENDIX C


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : CALGARY
TYPE : 6
TABLE : 6 APPENDIX C


NORTH AMERICA
Lambert Azimuthal Equal-area Projection
SURFACE PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 6
TABLE : 6 APPENDIX C

FIGURE 7.4


25%
75%
NORTH AMERICA
Lambert Azimuthal Equal area Projection
500 MB. PERCENTAGE AREAS
STATION : EDMONTON
TYPE : 6
TABLE : 6 APPENDIX D


75%
25%
NORTH AMERICA
Lambert Azimuthal Equal area Projection
500 MB. PERCENTAGE AREAS
STATION : CALGARY
TYPE : 6
TABLE : 6 APPENDIX D


25%
75%
NORTH AMERICA
Lambert Azimuthal Equal area Projection
500 MB. PERCENTAGE AREAS
STATION : LETHBRIDGE
TYPE : 6
TABLE : 6 APPENDIX D

FIGURE 7.5

TYPE VII

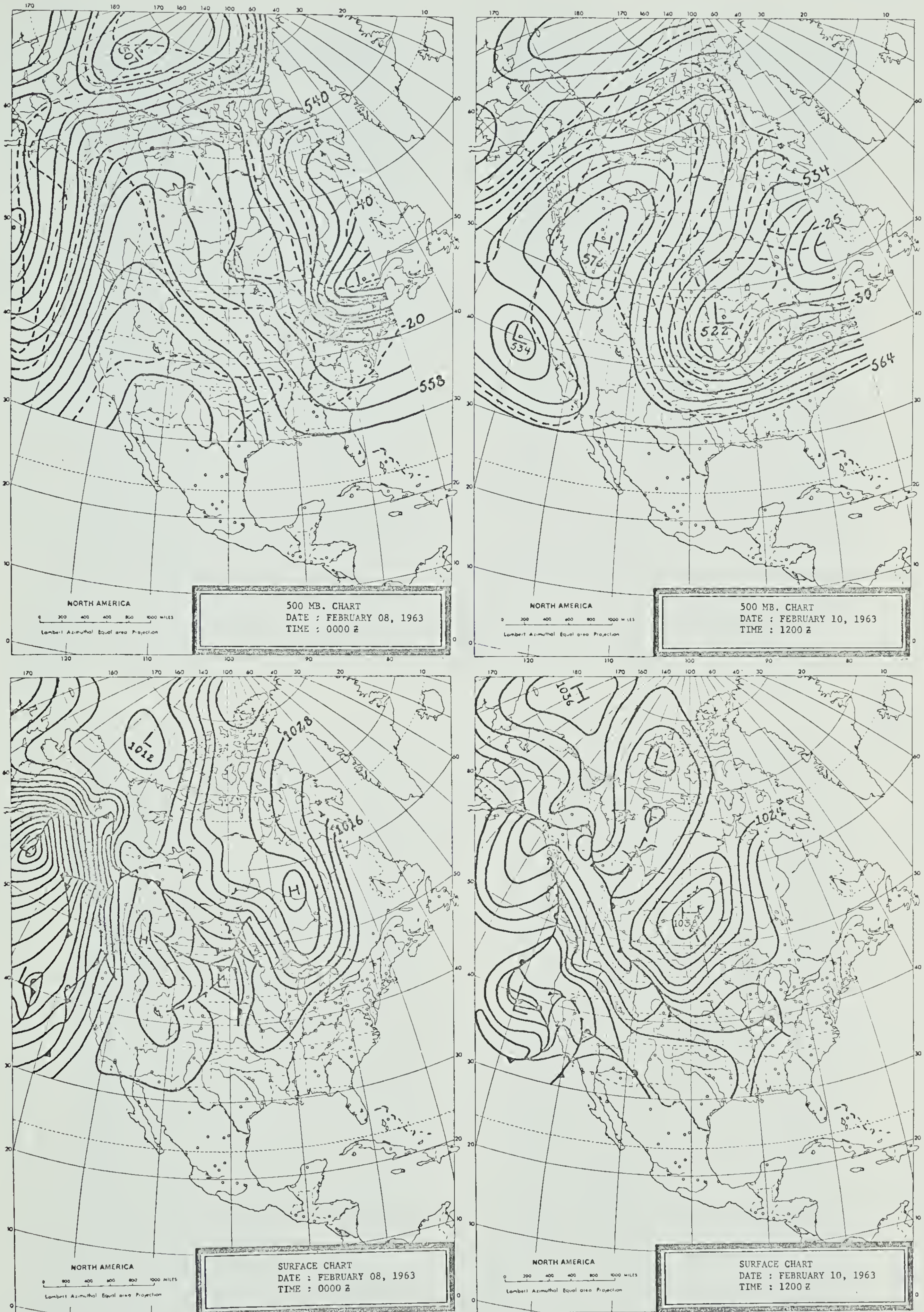

NORTH AMERICA
Lambert Azimuthal Equal area Projection
500 MB. CHART
DATE : FEBRUARY 08, 1963
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal area Projection
500 MB. CHART
DATE : FEBRUARY 10, 1963
TIME : 1200 Z
NORTH AMERICA
Lambert Azimuthal Equal area Projection
SURFACE CHART
DATE : FEBRUARY 08, 1963
TIME : 0000 Z
NORTH AMERICA
Lambert Azimuthal Equal area Projection
SURFACE CHART
DATE : FEBRUARY 10, 1963
TIME : 1200 Z

FIGURE 8.1

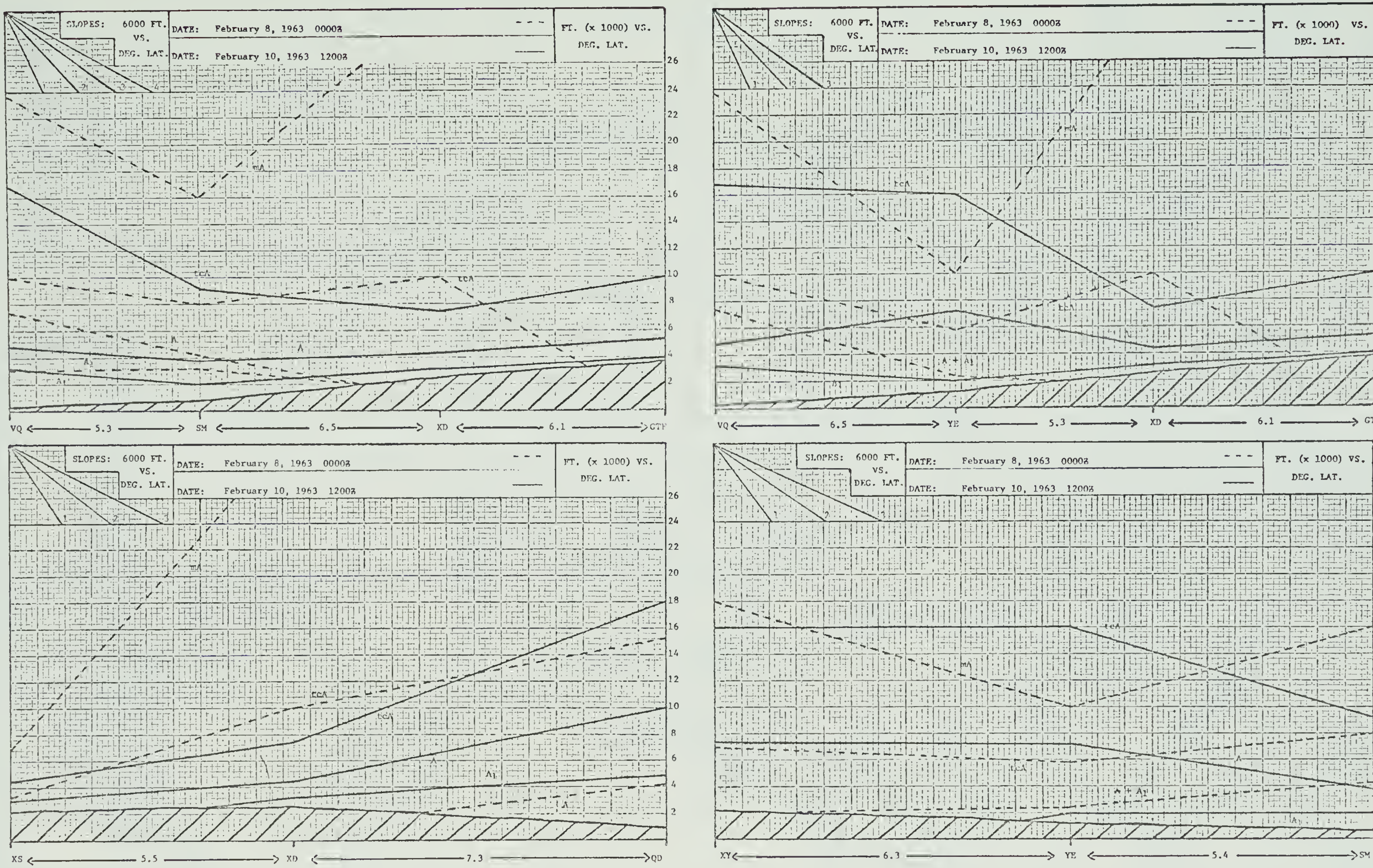

SLOPES: 6000 FT. VS. DEG. LAT.
DATE: February 8, 1963 0000Z
DATE: February 10, 1963 1200Z
FT. (x 1000) VS. DEG. LAT.
VQ ← 5.3 → SM ← 6.5 → XD ← 6.1 → GTF
VQ ← 6.5 → YE ← 5.3 → XD ← 6.1 → GTF
XS ← 5.5 → XD ← 7.3 → QD
XY ← 6.3 → YE ← 5.4 → SM

FIGURE 8.2

SURFACE HISTORY AND TRAJECTORIES

FIGURE 8.3

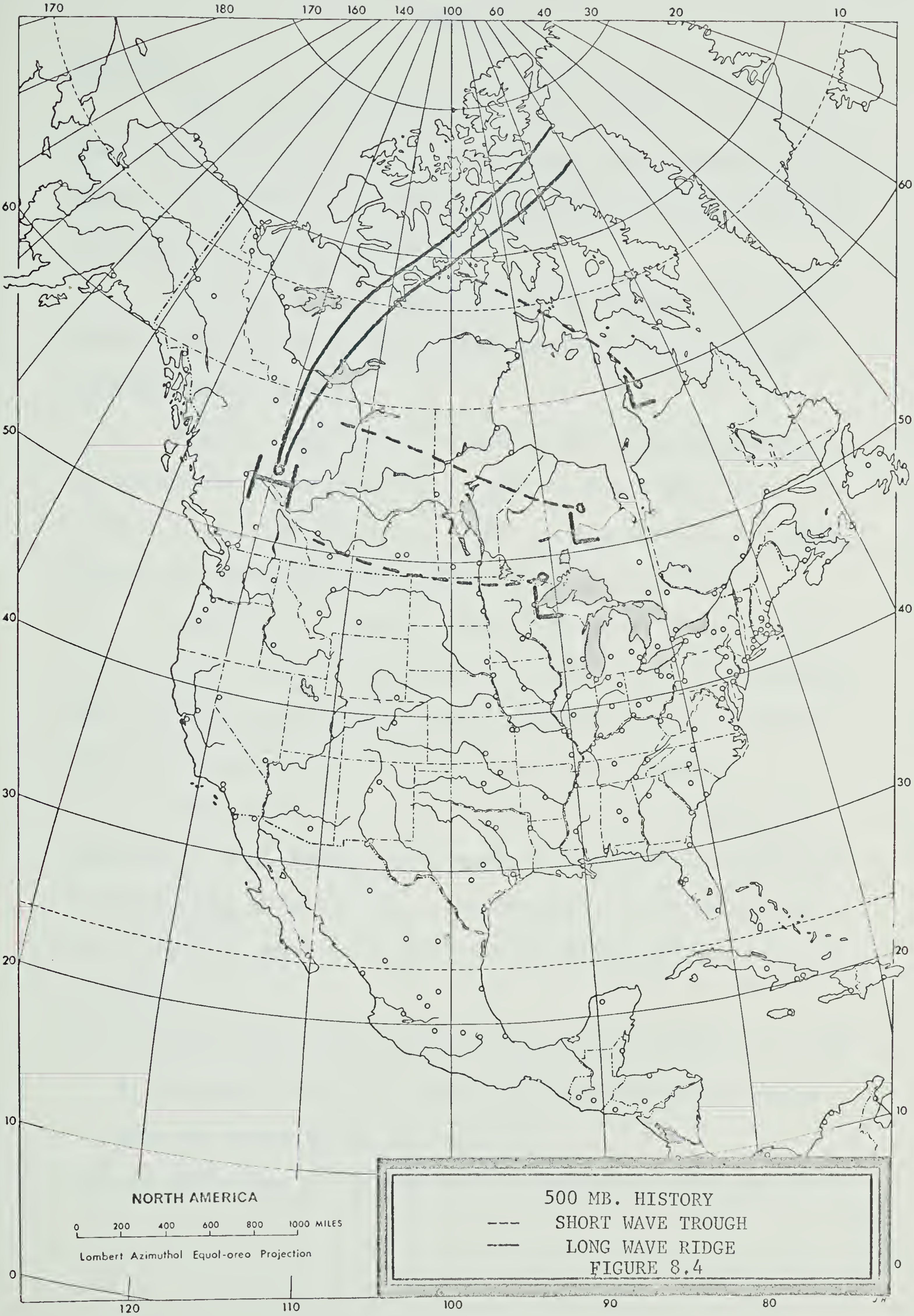

NORTH AMERICA
0 200 400 600 800 1000 MILES
Lambert Azimuthal Equal-area Projection
500 MB. HISTORY
--- SHORT WAVE TROUGH
—— LONG WAVE RIDGE

FIGURE 8.4

Application

Table 7 contains the period of time covered for all cases examined and classified. It may be seen that the period covered, in the mean, is slightly more than two days. This is an ideal range for the computer prognoses available.

The application of the method is essentially based on an analogue system and is to be used with the United States Weather Bureau prognostic charts.

Overlays, which are to be used on the prognostic charts, are constructed from Figures 2.3, .. etc .., 8.3, Figures 2.4, .. etc .., 7.4, and Figures 2.5, .. etc .., 7.5, 8.4, for each type, and from the data found in the tables of Appendices C andD .

The overlays constructed from Figures 2.3, .. etc .., 8.3, are as found in the text converted, of course, to the proper working scale. By using these overlays the forecaster may check the history and forecast trajectories of the relevent surface systems.

From Figures 2.4, .. etc .., 7.4 one first determines, by inspection of these figures, the center of the cluster as previously described. Then three overlays are constructed, to the proper scale, one for each of Edmonton, Calgary, and Lethbridge, and for each type as follows:

(1) from the center, using the radii listed in the tables of Appendix F, concentric circles are drawn with dashed lines and labeled with the listed percentage enclosure;

(2) the areas shown on the figures are then put on with solid lines

PERIOD OF TIME COVERED (HRS.)

							TYPE					
	1		1		1		2	3	4	5	6	7
CASE		CASE		CASE		CASE						
1	60	11	48	21	24	1	36	36	48	48	48	60
2	48	12	36	22	48	2	36	60	48	72	48	
3	48	13	48	23	48	3	48		60	72	48	
4	48	14	60	24	36	4	48		48	48	48	
5	24	15	48	25	48	5	72		108			
6	36	16	48	26	36	6	48		72			
7	48	17	48	27	48	7	48					
8	48	18	72	28	48	8						
9	60	19	24	29	36	9						
10	36	20	60			10						

ALL CASES

MEAN 50

STD. DEV. 14

TABLE 7

and their percentage enclosure, as listed in Appendix C, are placed within the area so described.

The Figure 9.1 illustrates this technique.

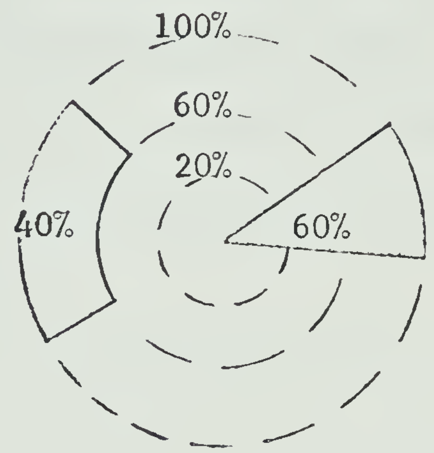


Figure 9.1

The procedure is identical, using Appendix D, for Figures 2.5, .. etc .., 8.4, as for the previously described figures. However, for the Figures 2.5, .. etc .., 8.4, the long wave ridge and short wave trough positions with their respective percentage enclosures are added to the overlays. The Figure 9.2 illustrates the final product.

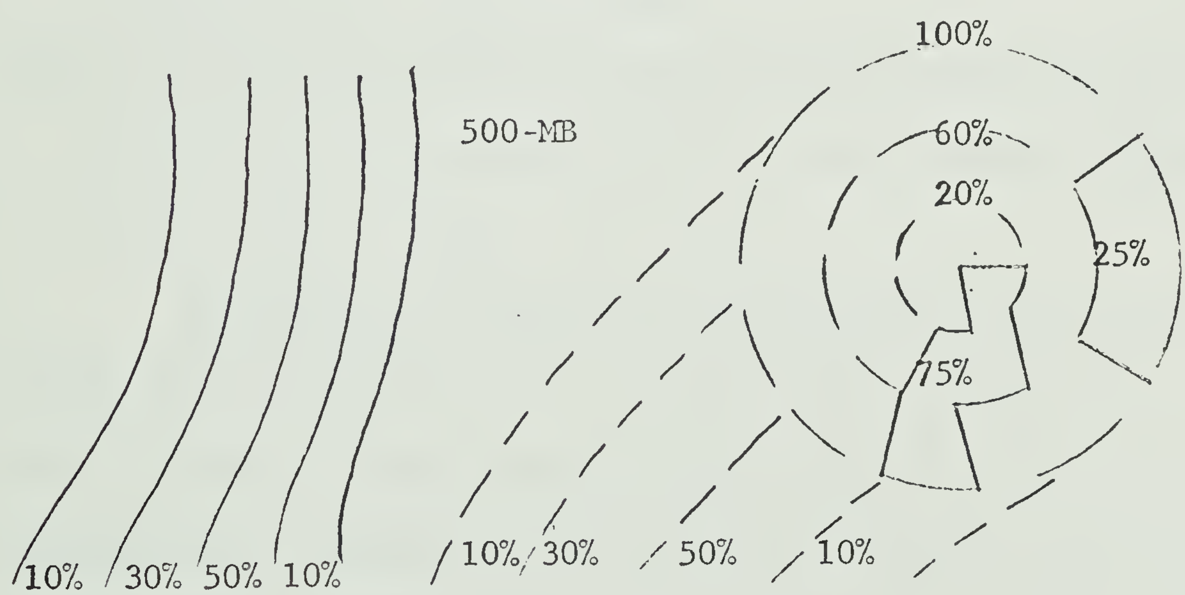


Figure 9.2

As was previously noted, the evaluation of the parameters near the boundaries of the designated areas may result in a poor forecast. It was for this reason that both the concentric circles and odd shaped areas were included. This enables the forecaster to determine the degree of confidence with which he may predict the occurrence and time of arctic frontal passage. As stated in Chapter 1 there are generally six parameters to be evaluated. For example, a high confidence could be as follows:

(1) the trajectories, both historical and predicted, of the surface systems fall within the 80 per-cent enclosure (Figures 2.3, .. etc .., 8.3);

(2) the predicted positions of the pertinent surface pressure features fall within the 80 per-cent enclosure circle and in or near a designated area (Figures 2.4, .. etc .., 7.4);

(3) the predicted position of the cold low falls within the 80 per-cent enclosure circle and in or near a designated area (Figures 2.5, .. etc .., 8.4);

(4) the predicted position of the short wave trough and the long wave ridge falls within the 80 per-cent enclosure (Figures 2.5, .. etc .., 8.4).

A preliminary selection of the type of arctic frontal passage may be made by referring to the example charts (Figures 2.1, .. etc .., 8.1) of Chapter 2, and comparing these with the current and forecast configurations. Secondly, by using Table 6, one may compare those criteria which classify a particular type to the existing current and prognostic charts. Lastly, by applying the overlays of Figures

2.3, .. etc .., 8.3, 2.4, .. etc .., 7.4, and 2.5, .. etc .., 7.5, 8.4, to the prognostic charts, it should be possible to make a final choice in the establishment of one of the seven synoptic types, and to predict the time of arctic frontal passage based on the position of the pertinent surface and 500-mb features. It must be kept in mind that the examples given are representative cases of each type and that a fair degree of variation may be expected within a given type.

It would be profitable, in future studies of this nature, to include the 850-mb, 700-mb, and 300-mb charts. The use of vorticity data would, no doubt, increase the accuracy and usefulness of the technique.

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INDEX

Appendices : Type I Through Type VII

A P P E N D I X A

Tables of Indexes of Cases Studied

INDEX

TYPE 1

CASE		CASE	
1	January 10-13 1958	16	November 6-8 1960
2	February 24-26 1958	17	December 13-15 1960
3	November 19-23 1958	18	December 17-20 1960
4	December 2-4 1958	19	January 27-28 1961
5	January 13-14 1959	20	February 2-4 1962
6	January 17-18 1959	21	December 21-22 1962
7	January 28-30 1959	22	January 7-9 1963
8	February 2-4 1959	23	January 11-13 1963
9	November 1-4 1959	24	January 16-17 1963
10	November 9-10 1959	25	January 19-22 1963
11	November 13-14 1959	26	January 27-28 1963
12	December 29-31 1959	27	February 16-17 1963
13	January 1-3 1960	28	December 7-9 1963
14	February 7-9 1960	29	December 11-12 1963
15	February 16-18 1960		

TABLE 1

INDEX

TYPE 2

CASE		CASE	
1	January 24-25 1960	5	December 8-11 1962
2	November 13-15 1961	6	January 6-8 1964
3	November 26-28 1961	7	November 16-18 1964
4	December 16-18 1961		

TABLE 2

TYPE 3

CASE	
1	December-January 31-01 1958-1959
2	January 5-9 1962

TABLE 3

TYPE 4

CASE		CASE	
1	January 23-25 1958	4	December 3-5 1960
2	February 1-3 1958	5	November 14-18 1963
3	November 12-14 1958	6	November 22-25 1964

TABLE 4

INDEX

TYPE 5

CASE		CASE	
1	January 5-7 1961	3	January 23-26 1962
2	February 10-13 1961	4	January 9-11 1964

TABLE 5

TYPE 6

CASE	
1	January 16-18 1960
2	October-November 31-02 1961
3	November 12-14 1964
4	December 9-11 1964

TABLE 6

TYPE 7

CASE	
1	February 8-10 1963

TABLE 7

APPENDIX B

Tables of Time Averaging

TYPE 1	XD		YC		QL	
		2/3 Δt		2/3 Δt		2/3 Δt
CASE	Δt	Δt/2	Δt	Δt/2	Δt	Δt/2
1	0	0	0	0	0	0
2	18	12	18	12	18	12
3	0	0	0	0	0	0
4	10	5	12	6	12	6
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	3	1.5	4	2	6	3
9	6	3	7	3.5	9	4.5
10	6	3	6	3	6	3
11	0	0	0	0	0	0
12	4	2	4	2	4	2
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	13	8.5	12	6	12	6
16	11	5.5	13	8.5	12	6
17	6	3	6	3	6	3
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	4	2	3	1.5	4	2
21	3	1.5	3	1.5	4	2
22	0	0	18	12	18	12
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	3	1.5	3	1.5	4	2

TABLE 1

TYPE 2 CASE	XD Δt	XD 2/3 Δt / $\Delta t/2$	YC Δt	YC 2/3 Δt / $\Delta t/2$	QL Δt	QL 2/3 Δt / $\Delta t/2$
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0

TABLE 2

TYPE 3 CASE						
1	0	0	0	0	0	0
2	0	0	0	0	0	0

TABLE 3

TYPE 4 CASE						
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	6	3	6	3	6	3
5	0	0	12	6	4	2
6	0	0	0	0	0	0

TABLE 4

TYPE 5 CASE	XD Δt	XD 2/3 Δt $\Delta t/2$	YC Δt	YC 2/3 Δt $\Delta t/2$	QL Δt	QL 2/3 Δt $\Delta t/2$
1	0	0	0	0	0	0
2	14	9	14	9	14	9
3	0	0	0	0	0	0
4	0	0	0	0	0	0

TABLE 5

TYPE 6 CASE						
1	0	0	0	0	0	0
2	3	1.5	3	1.5	3	1.5
3	0	0	0	0	0	0
4	0	0	0	0	0	0

TABLE 6

TYPE 7 CASE						
1	0	0	0	0	0	0

TABLE 7

A P P E N D I X   C

Tables of Radius and Percentage Enclosure
{ Surface }

TYPE 1 SURFACE	QL				YC				XD			
	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed
NORTHERN HIGH	2	38	1	28	2	29	1	28	1	3	1	24
	3	38	2	52	3	34	2	20	2	20	2	20
	3.5	48	3	20	4	62	3	52	3	38	3	55
	4	55			5	73			4	55		
	5	73			5.5	90			5	79		
	5.5	86			6	97			5.5	90		
	6	97			7	100			6	93		
	7	100							7	100		
SOUTHERN HIGH	3	39	1	9	2	9	1	22	2	9	1	4
	3.5	57	2	82	3	30	2	13	3	17	2	13
	4	65	3	9	4	70	3	65	4	52	3	13
	5	83			5	78			5	70	4	70

TABLE 1 (cont)

TYPE 1 SURFACE	QL				YC				XD			
	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed
	7	91			6	83			6	78		
	11	100			7	91			6.5	83		
					9	96			7	91		
					11	100			8	96		
									11	100		
LOW	2	10	1	11	2	10	1	90	1	17	1	3
	3	24	2	4	3	38	2	3	2	41	2	70
	4	48	3	4	3.5	58	3	7	2.5	52	3	14
	4.5	55	4	7	4	70			3	58	4	10
	5	76	5	7	5	83			4	62	5	3
	5.5	86	6	67	6	86			5	83		
	7	93			7	90			6	86		

TABLE 1

TYPE 1 SURFACE	QL				YC				XD			
	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed
	11	100			10	93			8	97		
					12	100			10	100		
					TABLE 1							
TYPE 2												
HIGH	1	14	1	57	1	43	1	48	1	14	1	29
	1.5	43	2	43	3	100	2	14	4	57	2	14
	3	100					3	48	5	71	3	14
									6	100	4	29
											5	14

TABLE 2 (cont)

TYPE 2 SURFACE	QL				YC				XD			
	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed
LOW	1	57	1	58	2	57	1	72	3	57	1	72
	3.5	100	2	14	5	85	2	14	4	100	2	14
			3	14	7	100	3	14			3	14
			4	14								
WAVE	2	14	1	72	2	43	1	72	1	28	1	72
	3	42	2	14	3	72	2	14	2	57	2	14
	4	70	3	14	5	100	3	14	4	100	3	14
	5	84										
	7	100										

TABLE 2

TYPE 3 SURFACE	QL				YC				XD			
	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed
NORTHERN HIGH	1	100	1	100	1	100	1	100	1	100	1	100
NORTHERN LOW	1	100	2	100	1	100	2	100	1	100	2	100
SOUTHERN LOW	1	100	3	100	1	100	3	100	1	100	3	100
SOUTHERN HIGH	1	100	4	100	1	100	4	100	1	100	4	100

TABLE 3

TYPE 4 SURFACE	QL				YC				XD			
	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed
HIGH	1	34	1	16	2	34	1	16	1	34	1	16
	2	68	2	16	3	68	2	16	2	50	2	34
	4	84	3	68	4	84	3	68	1	16	3	34
	6	100			6	100			2	50	4	16
LOW	1	17	1	16	1	50	1	17	1	50	1	16
	2	50	2	34	2	68	2	83	3	84	2	17
	3	85	3	50	3	84			7	100	3	50
	10	100			8	100					4	17

TABLE 4

TYPE 5 SURFACE	QL				YC				XD			
	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed
NORTH-WESTERN HIGH	1	50	1	50	1	50	1	50	2	50	1	50
	3.5	50	2	50	3.5	50	2	50	3.5	50	2	50
EASTERN HIGH	1	25	1	50	1	25	1	50	1	25	1	50
	2	50	2	25	2	50	2	25	3	50	2	25
	4	100	3	25	4	100	3	25	5	100	3	25
LOW	1	50	1	50	1	25	1	25	1	50	1	25
	3	75	2	25	2	75	2	75	4	100	2	25
	4	100	3	25	3	100					3	50

TABLE 5

TYPE 6 SURFACE	QL				YC				XD			
	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed
HIGH	2	25	1	75	1	50	1	50	1.5	50	1	50
	3	75	2	25	2	50	2	50	1	50	2	50
	9	100										
LOW	1	25	1	75	1	75	1	100	0.5	25	1	100
	1.5	75	2	25	3	100			1	50		
	5	100							1.5	100		

TABLE 6

A P P E N D I X D

Tables of Radius and Percentage Enclosure
{ 500 MB. }

TYPE 1 500 MB.	QL				YC				XD			
COLD LOW	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed
	2	17	1	20	2	20	1	10	2	17	1	10
	3	30	2	20	3	29	2	7	3	29	2	3
	4	52	3	60	4	41	3	7	4	41	3	67
	5	66			4.5	58	4	66	5	48	4	3
	6	79			5	66	5	10	5.5	66	5	17
	7	86			6	79			6	79		
	8	100			7	79			8	90		
					8	90			11	100		
					9	93						
					10	100						

TABLE 1

TYPE 2 500 MB.	QL				YC				XD			
COLD LOW	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed
	1	14	1	42	2	28	1	44	3	14	1	28
	2	28	2	28	6	56	2	28	4	28	2	28
	4	42	3	14	7	100	3	28	6	56	3	44
	6	100	4	14					9	100		

TABLE 2

TYPE 3												
NORTHERN COLD LOW	1	100	1	100	1	100	1	100	1	100	1	100
SOUTHERN COLD LOW	1.5	100	2	100	1.5	100	2	100	1.5	100	2	100
HIGH	1.5	100	3	100	1.5	100	3	100	1.5	100	3	100

TABLE 3

TYPE 4 500 MB.	QL				YC				XD			
COLD LOW	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed	Radius Degrees Latitude	Percentage Enclosed	Area	Percentage Enclosed
NORTHERN	1	17	1	17	4	34	1	17	4	34	1	16
	2	34	2	17	5	50	2	33	6	49	2	34
	3	50	3	50	6	83	3	33	7	84	3	34
	6	83	4	16	11	100	4	17	11	100	4	16
	10	100										
SOUTHERN	2	33	1	17	2	50	1	17	2	17	1	16
	3	50	2	83	3	100	2	83	3	50	2	34
	3.5	100							4	83	3	34
									5	100	4	16

TABLE 4

TYPE 5 500 MB.	QL				YC				XD			
COLD LOW	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed	Radius Degrees Latitude	Per-centage Enclosed	Area	Per-centage Enclosed
	2	50	1	25	2	75	1	25	2	25	1	25
	3	75	2	25	7	100	2	25	3	75	2	25
	7	100	3	50			3	50	7	100	3	25
											4	25

TABLE 5

TYPE 6												
COLD LOW	3	25	1	50	3	25	1	50	3	25	1	25
	5	75	2	25	5	50	2	50	5	50	2	25
	8	100	3	25	6	100			6	100	3	25
											4	25

TABLE 6